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SANITATION AND PERSONAL HYGIENE DURING AEROSPACE MISSIONS

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6570th AEROSPACE MEDICAL RESEARCH LABORATORIES
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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Contract Monitor: Albert Hearld
Life Support Systems Laboratory
Project No. 6373, Task No. 637304

(Prepared under Contract No. AF 33(616)-7754
by Rudolf H. Mattoni, Ph.D. and George H. Sullivan, M.D.
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FOREWORD

This report was prepared at Spacelabs, Inc., Van Nuys, California, where the authors are respectively Senior Research Scientist and Medical Director. The study, research, and development of the prototype system were carried out under Contract AF33(616)-7754 administered by the 6570th Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio. The contract monitor, Mr. Albert Hearld, Accommodations Section, Life Support Systems Laboratory, initiated this study, which supports Project 6373 "Equipment for Life Support in Aerospace, Task 637304 "Waste Recovery and Utilization." Work on this study was conducted between 22 November 1960 and 30 September 1961.

The authors acknowledge the advice, contributions, and constructive criticisms of a large number of people. Those who contributed time and interest to a far more than routine extent were Dr. Maurice S. Schaeffer, consulting psychologist; Prof. R. A. Kuever, dean emeritus, College of Pharmacy, State University of Iowa; Mr. Arthur Thompson, graduate student at Valley State College; Mr. Jack Wess of American-Viscose Company; Dr. Frederick Shillito of American Can Co.; Mr. J. R. Mitchell of Proctor and Gamble; Mr. Charles Lemoyne of Van Nuys Orthopedic Center; and Mr. Beverly Bond of Ronson Corporation.

ABSTRACT

The purpose of this study was to determine a means of providing astronauts with facilities for performing the functions of personal hygiene and sanitation while on extended aerospace missions. Included is a definition and analysis of the sources of "dirt" arising as waste products in manned space vehicles and recommendations on how to control them. Man's sanitation and hygiene requirements are defined from both a biological and psychological standpoint. A central hygiene station that provides for whole body immersion bathing, superficial bathing, dental hygiene, shaving, nail care, and laundry is described.

PUBLICATION REVIEW

This Technical Documentary Report has been reviewed and is approved.

Robert W. Roundy

ROBERT W. ROUNDY
Acting Chief
Life Support Systems Laboratory

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SECTION I

INTRODUCTION

GENERAL

During space travel man will be confined to small closed vehicles for considerable durations of time. Among the physical and psychological necessities will be avoidance of the perils of microbial infection and intoxication, and provision to live in relative cleanliness. The purpose of this study was to survey the materials produced as wastes by human metabolism and to design and fabricate a system for removing them - a sanitation and personal hygiene system.

The problem is to a degree psychological in nature. Submarine crews during World War II demonstrated that men can endure essentially closed environments for prolonged periods with no impairment to health. Since that time, considerable research has been carried out regarding the ability of man to function effectively under a variety of stresses. It can be concluded from these observations that human effectiveness can be maximized in an environment most closely resembling the familiar.

A sanitation and personal hygiene system should be constructed that most nearly provides for personal hygiene in an accustomed manner. Many familiar products are available for fulfilling sanitary and hygienic needs. From their evaluation, a system has been designed incorporating selected items. This system meets the hygienic and sanitary requirements while satisfying the psychological conditioning to which the average American male has been subjected.

For the purposes of this report, sanitation is defined as the process of keeping the interior of the vehicle and its equipment free of noxious odors and particles potentially injurious to health. The treatment of feces, urine, and garbage is not included in the scope of this report. Personal hygiene encompasses those processes of maintaining body cleanliness, dental care, removing surplus hairs and nails, and providing clean clothing.

OBJECTIVES

The objectives of this study were: (1) to compile a comprehensive report qualitatively defining and quantitatively estimating human wastes that will be generated in a closed system, (2) to consider the general hygienic and sanitation problems to be solved for maintaining man in a closed system, and (3) to specify, fabricate, and assemble a system of materials and equipment to fulfill the sanitation and hygienic requirements of high performance missions.

OPERATING CONDITIONS

The conditions in which the sanitation and hygiene system will operate have been defined as follows: (1) cabin pressures will range between 1/2 to 1 atmosphere, (2) cabin temperatures will be maintained at $77° \pm 18°F$, a "shirt sleeve" environment will prevail, (3) the gravitational forces will be 0 g, and (4) radiation will be within established occupational limits.

SYSTEM REQUIREMENTS

The system must be operable at all times under the range of conditions specified above. In addition, it must be designed to accommodate a crew of from one to six men for a flight duration of 7-60 days. The evaluation will cover the minimum requirements for any number of crew members for that duration. Power, space, and weight should be held to a minimum consistent with operating capabilities.

SECTION II

WASTE PRODUCTS, COMPOSITION AND RATE OF PRODUCTION

SCOPE OF PRODUCTS

A manned space vehicle will contain and produce a number of materials in all physical states. Some may produce a spectrum of physiological responses from almost undetectable alterations of behavioral patterns, through a variety of impairments of performance based on many etiologies to cessation of consciousness or even loss of life itself. Others are required for maintaining human life, or at least may be physiologically useful. The remainder are biologically inert. Materials of physiological significance from all sources in a manned space vehicle will be considered from a standpoint of a mass that must be handled by the proposed system and other immediately integrated systems (e.g., air conditioning, gas exchange). The bulk of unused food (as garbage), urine, and feces are handled by other systems that lie beyond the definition of this program. The materials with which the program will deal are derived from three principal sources:

1. Vehicle Structure and Equipment
2. Foods
3. Body Materials.

Vehicle Structure and Equipment

This category includes all materials not given off by man, his microbial associates, and food. A complete listing of these materials cannot be made at this time because of variables and unknowns. Many will not be handled by the sanitation and personal hygiene system because of their physical state.

Substances that will be handled by the sanitation and personal hygiene system include dusts from surfaces of all materials due to oxidation and volitilization; lubricants that escape as liquids and gases; oil residues from machining processes; organics that volatilize; plastics and elastomeres that lose catalysts and incompletely polymerized monomers; coatings that may flake and give off all kinds of volatile gases and expose films on the surfaces; and cleansing compounds of this system itself. Some oxygen regenerative systems may add to the chemical complexities; and clothing may give off lints, volatile compounds, and have allergenic properties.

We estimated the total quantity of materials eminating from the cabin sources will not exceed an estimated 0.7 gm/man/day. This estimate would be expected to diminish on a man per day basis with increase in crew size.

Food Spillage

Food spillage is another source of material that must be removed. The composition and quantity of wastes arising from this source are unknown. It can be assumed, however, that the only dietary component subject to spillage will be liquid. Any accidentally "dropped" particulate food may be mechanically retrieved and disposed of. Whatever small particles elude recovery can be generally treated as a dispersed liquid.

The weightless condition may bring about loss of food purely by accidents associated with the timing of cardiac valve openings and reverse peristalsis. Frequency of vomiting during long duration flight is impossible to ascertain. The amount and composition of vomitus depends upon the nature of the food and its state of digestion in the stomach at the onset of vomiting. The quantity regurgitated varies between 30 and 300 ml per event, based on citations found in standard medical texts. Assuming 30 ml vomitus per man per 60-day mission, an average of 0.5 gm/man/day can be projected. This figure is incorporated in the estimate for total food spillage.

Conceivably food containers will be accidentally opened or broken. An adequate sanitation system must provide for the removal and disposal of products released during accidents. We estimate the average production of wastes in this category will not exceed 0.7 gm/man/day.

Body Materials

The largest consistently generated classes of wastes of humans are those produced by metabolic functioning. The bulk of these wastes are contained in the urine and feces. The remainder of the wastes are those emanating from the skin and orifices of the body. They are, with the exception of the body microflora and flatus, of epithelial origin. These products are:

1. The skin and its appendages
   a. Desquamated epithelium
   b. Hair
   c. Nails
2. Glandular secretions
   a. Sweat
   b. Sebaceous execretion (sebum)
   c. Saliva
   d. Mucus
   e. Seminal fluid
3. Microflora and microbial products
   a. Flatus
   b. Microflora
   c. Microbial products.

The sanitation and personal hygiene system described in this report has been designed to remove these products. Operationally it will also remove fecal particles. Their quantity, though almost negligible, must be considered.

Desquamated Epithelium - The outer layer of the skin acts as a physical barrier to invasion by microorganisms and penetration by injurious compounds. It is constantly being formed by fundamental cells in the lower germinative layers of the epidermis — a process reciprocated by its continual shedding as small particles from the surface. The layer is shed as small particles, referred to as desquamated epithelium. Agitation or abrasion by rubbing hasten the process.

The rate of desquamation has been determined by a number of investigators

(References 4 and 6). The rate is directly proportional to the renewal time, which has been found to vary between 7 and 36 days. This variation is based on rate of epithelial removal by abrasive action (not to be confused with rubbing), temperature dependence, and doubtless hereditary differences. The average replacement rate of Storey and Leblond (Reference 22) is given as 19.1 days. This value probably varies in different parts of the body. They also determined that division rates of the germinative cells in rats varied from 0.33% at 10-12°C, to 0.47% at 20-22°C and 2.96% at 25-30°C. If the same phenomenon holds true for man, the cabin thermal conditions will be important in affecting the quantity of epithelial debris that must be handled. Taking 19 days as the average replacement rate, 0.05 mm as the average thickness of the cornified layer, and 1.8 M^2 as the total body area, we can calculate that 5.0 cc/day/man of desquamated epithelium is produced.

The 19 day figure was obtained using abrasive removal by scotch tape at room temperatures. Rothman (Reference 19) estimates nonabrasive shedding rates of 32-36 days. A 32-day replacement rate gives 2.8 cc/man/day. The resultant weights of material would be about 5.5 grams in the first and 3.0 grams in the second cases. In the synoptic Table of Wastes (Table 6) 3.0 gm/man/day is given having a volume of 2.8 cc/man/day. Extrapolation from two sources, temperature dependence and abrasive action of clothing, indicates this is probably a minimum value. However, it can be surmised that the epithelium removed by abrasive action of clothes will not be handled in bathing, but will be lost directly to the cabin atmosphere in a closed system. Desquamated epithelium appears to be one of the largest sources of directly generated human waste to be considered by this program.

Hair - Hairs are distributed over almost the entire body, but there is wide variation in frequency and type, not only between different regions on any given individual, but between individuals as well. Hairs are absent only from the lip margins, glans penis, and flexor surfaces of the hands and feet. They have a mechanically protective function in areas of high frequency: the scalp, pubis, and axilla. They are also of significance as general insulating mechanisms.

Hairs grow and are replaced regularly. There is some evidence that the hair serves as an excretory organ for a number of minerals. Two important aspects of hair biology are of concern here, growth rate and replacement rate. Table 1 presents data of growth rates and regenerations times of hairs of various parts of the human body. The former are from observations of Myers and Hamilton (Reference 17) and the latter from Flesch (cited in Reference 19). Depending on the frequency, volume, and density of hair, the quantity generated by both growth and whole hair loss (depilation) can now be calculated. The hair frequency varies from a maximum density of 300/cm^2 on the scalp and chin to 0 on the flexor surfaces. An average is about 20/cm^2 for the whole body. Assuming an average body area of 1.8 M^2 and an average hair life span of 12 months, it can be calculated that depilation amounts to about 1000 hairs per day. This figure is comprised mostly of down hairs, which escape unnoticed in our terrestrial experiences - recalling that from Flesch's data, the loss of crown hairs only amounts to about 40 per day. In reference to the capacities of a sanitation system relative to hair removal, assuming an average volume of 0.025 cu. mm per hair and a specific gravity of 1.057, the total weight of hair lost by dipilation will amount to about 27 mg or 0.03 gm/man/day, and a volume of about 0.03 cc.

TABLE 1

GROWTH RATE OF HUMAN KERATINOUS APPENDAGES AND REGENERATION TIME OF HUMAN HAIR

	GROWTH RATE(mm/Day)	REGENERATION RATE
HAIR - REGION		
Crown	.30	4 - 6 Years
Supraear	.32	
Axilla	.36	202 Days
Thigh	.16	
Chin	.42 (.54 in Summer)	7 - 11 Months
Cilia	.14	150 Days
Chest		124 - 210 Days
Pubis		20 - 35 Months
FINGERNAILS	1 mm/Week	
THUMBNAILS	1.2 mm/Week	
TOENAILS	0.25 mm/Week	

There are no data available as to variations in dipilation rates under different environmental conditions, except radiation effects. Temperature changes undoubtedly induce differences, but for practical consideration under the flight durations specified, any effects would be negligible. The effects of ionizing radiations on hair replacement have been reported by Ellinger (Reference 5). He showed that the rate of depilation increased with exposure to x-rays of varying intensities and duration. It may prove fruitful to consider a device that would quantify hair loss rates of astronauts as a dosimetric index. It is furthermore not inconceivable that radiations at the upper limits of occupational acceptance would be sufficient to produce significant increases in the rate of hair loss.

Table 1 gives data on the growth rates of various human hairs. The only consequential components here are the facial and chin hairs, which will be subject to removal by shaving. Based on the observed value of 0.42 mm growth/day, about 100 sq. cm of area, density of 300 hairs per square cm, and a diameter of 0.15 mm; it is calculated that the growth of facial and chin hair is equivalent to about 0.25 gm/day for the average mature male. Actual determination of facial hair mass produced per day from one of the authors (Mattoni) gave 0.28 gm/day and a volume of about 0.25 cc. The latter subject is apparently average in beard density and consistency. Variation in quantity of facial hair production is influenced by temperature as evidenced by a higher growth rate in warm environments. There is also variation among individuals. In the synoptic Table 6, 0.3 gm/man/day having a volume of about 0.28 cc is given as the best average estimate of hairs resulting from facial and chin growth.

Nails - Human nails occur on the distal fingers and toes, serving as protective devices on all digits and for use as tools on the fingers. The chemical composition of the nails is summarized in Spector (Reference 21). The nails are also derived from keritinized epithelial cells. Table 1 gives the growth rates of nails as determined by Storey and Leblond (Reference 22). There is no explanation for the difference between toe and fingernail growth. Given a growth rate of the fingernails as 1 mm/week, it can be calculated that the ten fingers of a man will produce 0.065 cc of nails per week weighing about 0.07 grams. The toenail production can be ignored from practical consideration since the slow growth rates are insufficient to demand treatment during the maximum defined mission.

Sweat - Sweat or perspiration is produced from two sources, sweat glands and directly by diffusion through the epidermis. The greatest quantity is produced by the sweat glands, the eccrine sweat glands and the apocrine sweat glands. The eccrine sweat glands are distributed over the whole body surface except on the nipple, glans penis, and lip margins. Apocrine sweat glands are limited to the axilla, areola, genitalia, and circumanal regions. The two kinds of glands differ in the composition of the sweat they excrete and in their size, the aprocrines being 2 to 5 times larger than the eccrines.

The composition of eccrine sweat is given in Table 2. These data are based on Reference 21, Rothman (Reference 19), and Kuno (Reference 14). Shelley (Reference 20) partially analyzed the composition of apocrine sweat, noting primarily its physical differences in being florescent and showing a higher pH. He also determined that offensive body odors were almost entirely produced by bacterial action on apocrine sweat. The quantity of ammonia produced in the axillary apocrine sweat, for instance, reached 78 mg/100 cc. Ammonia is an important component of body odor.

TABLE 2

CHEMICAL COMPOSITION OF HUMAN SWEAT

Values are in mg/100 ml unless otherwise indicated. Those in parentheses are ranges. Literature search indicates the high range figures are from the older literature and are probably due to inaccurate testing procedures. See text for further explanation.

Water %	(99.0 - 99.7)	Threonine	(1.7 - 9.1)
Calcium	(1.0 - 8.0)	Tryptophan	(.4 - 1.8)
Chloride	(30 - 300)	Tyrosine	(1.2 - 5.0)
Iodine, μ g	(.5 - 1.2)	Valine	(1.5 - 4.5)
Magnesium	(.14 - 4.5)	Reducing Substances, Glucose	(2.8 - 40.0)
Manganese, μg	(3 - 7)	Volatile Acids (ml 0.1 N)	(2.4 - 5.6)
Phosphorus	(0 - 2.0)	Lactic Acid	(45 - 452)
Potassium	(21 - 126)	Ascorbic Acid, μg	(0 - 200)
Sodium	(29 - 294)	Biotin, μg	Trace
Sulfur (incl. Sulfates)	(0.7 - 7.4)	Choline, μg	(0.3 - 1.5)
Iron, μg	(22 - 45)	Folic Acid Group, μg	(0.53 - 0.88)
Total Nitrogen	(27 - 64)	Inositol, μg	(15 - 36)
Amino Acid N.	(1.6 - 4.8)	Nicotinic Acid, μg	(7 - 22)
Ammonia	(2.5 - 35)	Pantothenic Acid, μg	(2.2 - 4.4)
Creatine & Creatinine	(0.1 - 1.3)	p-Aminobenzoic Acid, μg	(0.08 - 1.7)
Urea	(12 - 275)	Pyridoxine, μg	(0.08 - 0.18)
Uric Acid	(0.7 - 2.5)	Pyridoxal, μg	(.04 - 8.25)
Arginine	(5.8 - 21.4)	Riboflavin, μg	(0.0 - 0.5)
Histadine	(6 - 10)	Thiamin, μg	(0.0 - 0.6)
Isoleucine	(1.0 - 3.6)	Physical Characteristics, sp. gr.	(1.001 - 1.006)
Leucine	(1.2 - 4.2)	pH Apocrine Sweat	(5.0 - 6.5)
Lysine	(1.4 - 3.2)	pH Eccrine Sweat	(4.0 - 6.0)
Phenylalanine	(1.0 - 3.5)	Maximum Production, ml/min.	(17.7 - 38.2)

Changes in the rate of sweating due to thermoregulatory demands is manifested in changes in chemical composition of the sweat (References 3, 14, & 19). Dill et al (Reference 3), found that electrolytes (Na and Cl) increased during initial thermogenic heating, but later decreased in concentration, indicating acclimatization. Quality of the diet can also modify the composition of sweat, as a five-fold increase of urea in food will induce an eightfold increase in the urea of sweat.

A striking feature of Table 2 is the wide ranges observed for concentration of the various solid components of sweat. These are due to changes in quantity of sweat produced per unit time, differences in different regions of the body, individual variation, and diet.

The rate of sweating will determine, approximately, the quantity of solid residue deposited on the skin. A minimum solid residue as a result of sweating would be 0.5 gm/man/day if the assumption of one liter of sweat a day holds true (Reference 26). However, since sweat production is under complex autonomic control, responsive to emotional as well as thermoregulatory stimulation, this figure is probably half that actually to be realized. Furthermore, variations in solid concentration being what they are, 1 gram/liter may not be an optimistic estimate. We conclude that operationally 2 to 3 grams of solids will be realized from sweat under the conditions specified for this program. In calculating demands on our sanitation system 3 grams per day will be assumed, almost all of which is soluble, (Synoptic Table 6).

Sebaceous Excretion - The surface of the human skin is continuously covered by a thin film, which can be described as a half aqueous, half lipid homogeneous emulsion. The emulsifiers of this film are cholesterol and wax alcohols. The aqueous phase is contributed as water from the source of sweat. There are three main sources of the lipid, sebaceous phase: sebum, which is excreted by the sebaceous glands; that produced by keratinization; and lipid produced by apocrine excretion. The greatest quantity of sebum is produced by the sebaceous glands.

The chemical composition of sebum is given in Table 3. The data from which this table was constructed were derived from Reference 21 and Rothman (Reference 19). It has been demonstrated in Reference 19 that the lower chain unsaturated free fatty acids (particularly those with 6-10 carbons) are fungistatic. These have properties, therefore, in self-sterilizing the skin. The well known distribution of "Athletes Foot," tinea pedis, between the phalanges can be accounted for by the absence of sebaceous glands in the location which would otherwise provide sebum to affect fungus control.

The rate at which sebum is produced is complex, owing to a feedback mechanism of adaptive significance. As noted above, the surface film, particularly its lipid component, has several protective roles. To insure sufficient lipid present in the surface film, a constant quantity of sebum is always present on undisturbed skin. This quantity represents the so-called saturation level (Dunner, Reference 19). Depending on the region of the body, temperature, and other factors, the saturation levels vary around a mean density of about 0.5 mg/sq. cm., varying between 3.38 mg/sq. cm. and 0.035 mg/sq. cm. Among the causes of variation, temperature affects the saturation level primarily because below 30°C sebum solidifies. At lower temperatures (i.e. 2°C) the rapidly declining microcline of bodily thermal radiations prevents sebum from liquifying and its flow is stopped.

TABLE 3

CHEMICAL COMPOSITION OF HUMAN SEBUM

Values are in g/100 g unless otherwise indicated. Those in parentheses are ranges.

Fatty Acids, Free, Straight Chain	28.3 (22.0 - 50.0)
Fatty Acids, Combined, Straight Chain, Total	34.6 (27.5 - 41.0)
Triglycerides	32.5
Other	2.1
Unsaponifiable Material, Total	30.1 (25.1 - 35.9)
Squalene ($C_{30}H_{50}$)	5.5 (1.0 - 11.2)
Other Hydrocarbons	8.1 (5.0 - 20.0)
Aliphatic Alcohols	6.2 (4.7 - 6.9)
Straight Chained	2.4
Branched	3.8
Cholesterol	4.1 (2.7 - 6.9)
Vitamin E and Tocophenol	0.0002
Pro Vitamin D	1)
Vitamin A Precursors	1)

1) Bioligical evidence for presence, not chemical evidence

Whenever the saturation level is reduced, which in humans is almost entirely brought about by bathing and the abrasive action of clothing, an excretory mechanism is activated and operates to replace the quantity lost. The rate of replacement is called the production capacity, which varies per surface area depending on the frequency of gland openings. The production capacity is sufficient to replace any sebum removed from a given area in about 3 to 4 hours. Jones (in Reference 19) states that sebum is excreted at a minimal rate of 1 gamma/sq. cm./min. following defatting.

From the above data the saturation level of the body is calculated to amount to about 9 grams of sebum. Assuming one-sixteenth of this is removed by the clothing — to which it adheres—1.5 gm/man/day will result. The total sebum production, from these two sources will amount to 4 gm/man/day. This estimate is given in synoptic Table 6.

Saliva - Saliva is produced by three pairs of ducted salivary glands. A small quantity is also produced by buccal glands, which are widely distributed over the lining of the mouth.

The saliva is constantly generated to effect a flushing action in the mouth at all times. The quantity present in the mouth is determined by a sensory-effector autonomic feedback system. Immediately preceeding and during feeding, copious amounts of saliva are produced. The saliva produced is almost entirely washed into the digestive tract.

A certain quantity, however, is lost by sneezing, coughing, and talking (Reference 12). There is also a slight loss of saliva attendent to lip wetting, the solid deposits that will be absorbed in washing. Although these quantities are difficult to calculate, depending on individual reactions, we estimate that the solids will not exceed 10 mg/man/day, of which 8 mg will be expelled into the cabin atmosphere, leaving a residue of only 2 mg or 0.002 cc/man/day subject to removal from the body. The latter figure is the estimate given in the synoptic Table 6.

Mucus - Mucus is produced in the mucus bed of the nasopharyngeal passages. It protects the body, particularly the lower respiratory tract, from invasion by noxious agents and potentially infective microorganisms. The mucus bed is estimated (Reference 11) to catch some 75% of the bacteria contained in the inhaled air. In general, large particles are efficiently removed mechanically by the wet mucus surfaces, while small ones may not be retained at all.

The secretion of mucus is a continuous process. The absolute rate of secretion is determined by the quantity of particles or sensitizing compounds coming in contact with the mucous membranes. In the normal course of events the entire production of mucus travels down the digestive tract. The only external loss of mucus would occur if there were some source of irritation or infection. In the closed atmosphere of a space vehicle the bulk of potentially irritating particles will presumably be removed by an air purification system. Latent sources of viral or bacterial respiratory infection cannot be entirely discounted, however, and there will be occasional losses by sneezing and possibly disturbances induced by weightlessness.

In addition, mucus can be disgorged by strong odors, bright lights, chilling, and emotional stresses. We have estimated that the total quantity of solids resulting from all of these sources will average about 0.4 gm/man/day. These amounts

will fluctuate widely on a daily basis, however. The majority of the solids will be collected on spongecloth wipers so a minimum will escape into the cabin atmosphere.

Seminal Fluid - Small quantities of seminal fluid from the genital tract may be produced by accidental or subconscious discharge. The seminal fluid consists of spermatozoa plus fluid secreted by several glands, including the prostate gland. We estimate that the maximum solids generated from this source will be about 3 mg/man/day. These would be deposited on the genital area of the body and underclothing.

Urine - A quantity of about 0.10 to 0.20 cc urine is generally retained in the distal urethra following relief of the bladder, and gradually escapes to the exterior. Although this quantity may be minimized by development of training techniques and sophisticated plumbing in the urine treatment system, it is unlikely that elimination of such leakage will be completely effected. We estimate that an average of 0.50 cc/man/day will be lost. Since urine contains about 5% solids, this will amount to about 25 mg of solids per day which will be deposited in the genital area of the skin and clothing. The detailed composition of urine can be found in Reference 25.

Flatus - The metabolic activities of the microflora of the digestive tract produce a variety of gases. These gases cause intestinal distention which is relieved by chronic out gassing or sudden flatulation. The quantity and composition of flatus will depend on a number of factors, but these primarily include the numbers and kinds of alimentary microorganisms, the nature of the diet, and the physical environment of the lumen of the gut. The chemical composition of the gases in flatus has been determined by Kirk (Reference 13). The spectrum of variation of composition is noteworthy. Once a standard diet is specified for space operations, more precise determinations can be made.

Kirk also determined the quantity of flatus produced individually from 45 normal subjects. The average for this population was 1.47 ml/min ranging from 0.25 to 6.23 ml/min over a 5-10 hour test period. In another sample, 1.55 ml/min of flatus was produced in a group of hospital patients on a "normal" diet while 2.34 ml/min was produced by a group on a lactose and cabbage supplement. The latter data presents an insight into the effect of dietary factors on volume of production for a population.

For rate of flatus production, we estimate about 1.5 ml/min will be introduced into the cabin atmosphere under normal circumstances. This assumes a cabin pressure of one atmosphere. At the present state of knowledge it is difficult to extrapolate the effects of lower pressures. Multiplication gives 2 liters/man/day as the expected flatus production with a range of 0.41 to 9.01/man/day. Actual expression of flatus regularly occurs as a chronic outgassing, or leaking, which is more or less insensible; in addition to which are the more spectacular events of sporadic flatulation. The latter event is accompanied by expression of small fecal particles, water, and enteric microorganisms.

Fecal Particles - A consequence of the process of colonic evacuation will be a residuum of fecal debris adhering to the circumanal region. The quantity of this debris, which will consist of fecal wastes drying to small, hard, adherent particles, will depend on the techniques employed in collection of the fecal waste

TABLE 4

CHEMICAL COMPOSITION OF HUMAN FLATUS

In percent, first column gives means for twenty persons on an ordinary diet. Ranges of all subjects in parentheses. (After Kirk)

CO_2	9.0	(5.9 - 24.7)
O_2	3.9	(0.0 - 10.0)
CH_4	7.2	(0.0 - 34.1)
H_2	20.9	(0.0 - 37.2)
N_2	59.0	(24.7 - 87.7)
H_2S	0.0003	(0.0 - .00064)
Trace Gases	Not Recorded	

and subsequent cleaning. In terms of both personal hygiene and sanitation, these particles must be removed, as a large quantity of bacteria are constituents of this material. The composition of the fecal material will be determined by the alimentary environment of each individual, his diet, and his symbiotic microflora. A list of components of feces, both food wastes and bacterial composition are presented in Reference 21.

For the purposes of this report, we are concerned with the problem of fecal particles remaining after the techniques of primary removal immediately following evacuation. We estimate these will collect in the circumanal region at a rate that will not exceed 25 mg/man/day, the figure given in synoptic Table 6. A small quantity will also be expelled during flatulation.

Microorganisms - A number of species of microorganisms, primarily bacteria and fungi, are associated with the human body. These can be classified generally as two types: transient forms, which are usually pathogenic and come and go depending on their equilibrium with the micro-environmental conditions of the region of the body where they may land; and indigenous forms, which occur as more or less stable populations all the time on particular regions. These forms can be assumed to remain in residence on their characteristic sites, resisting the thorough personal cleansing individuals will receive prior to missile flight. These indigenous species range in virulence through a spectrum of completely nonpathogenic commensals to pathogenic forms in low frequency awaiting the opportunity to invade the body.

The microorganisms normally found on various surfaces of the human body are cataloged in Table 5, after that given by Rosebury (Reference 9). The most conspicious members found on the skin include Staphylococcus albus and Proprionibacterium (References 4 & 6); on all mucous membranes Staphylococcus, Streptococcus, and Candida, on the naso-pharyngeal area Neisseria and Corynebacterium; Treponema, Endameba gingivalis, and Actinomycetes of the mouth and throat; and the enteric bacilli, Pseudomonas, and Clostridium of the intestinal tract.

Strauss and Kligmann (Reference 23) attempted to identify the normal bacteria in the axillary region in order to define the causative agents producing body odor. We believe their category Diptheriods refers to Proprionibacterium, as the latter can be confused with Corynebacterium by several criteria. Proprionibacterium are known to reside in the sebaceous glands and, therefore, resist bathing action. The action of these bacteria in obtaining their energy by oxidizing the nitrogenous compounds of the skin is known to provide intermediary metabolites that we associate with body odor.

Several fungi and yeast-like organisms are associated with humans, in addition to Candida mentioned above (Reference 15). These produce superficial infections, Dermatomycoses, which are common to, but highly localized in, many individuals. These are usually forms of the genus Trichophyton, and includes the species responsible for athletes foot and severe dandruff. In general, these fungi are controlled by sterilizing compounds excreted by the skin.

The microorganisms of the skin are difficult if not impossible to remove completely. They resist bathing and abrasive action. Their numbers remain constant, however, although they escape onto the clothing where they grow in the presence of substrates liberated by the skin in the form of sweat, sebaceous, and epithelial debris. We estimate about 0.16 gm/man/day of microorganisms will be generated

TABLE 5

List of types of microorganisms indigenous to the human body. Relative abundance by region indicated by 1) Irregular, 2) Common or Constant, 3) Most Numerous. Underlined types universal to region.

	SKIN	EYE	NOSE	PHARYNX	MOUTH	INTESTINE	EXTERNAL GENITALIA
Micrococcus	1		1	1	1	1	1
Staphylococcus	2	1	1	2	1	1	1
Aerobic Micrococcus	2			1	2		1
Alpha, Gamma Streptococcus	1		1	3	3	2	1
Beta Streptococcus	1		1	1	1	2	
Anaerobic Streptococcus				1	2	1	1
Pneumococcus			1	1	1		
Neisseria			1	3	1		
Bacillus	1			1	1	1	
Clostridium						2	
Corynebacterium		1	2	1	1		2
Lactobacillus					2	2	
Proprionibacterium	3						
Actinomycetes				2	2	1	
Leptotrichia					2		
Myobacterium							2
Escherichia	1				1	3	2
Aerobacter						1	
Klebsiella						1	
Proteus					1	1	
Pseudomonas					1		
Hemophilus			1	1			
Dialister				1			
Bacteriodes				1	1	3	1
Fusobacterium				1	2	1	2
Anaerobic Vibrio				1	2	1	1
Spirochaetes				1	3	2	2
Fungi	1				2	1	1
Protozoa					1	1	1
Pleuro-Pneumonia Like Organisms				1	1		1

on the clothing and on the skin as a replacement of the populations removed during bathing. In addition, enteric bacteria deposited in fecal particles will be about 8 mg/man/day, which is included in the estimate given on page 10 under Fecal Particles. A certain number of bacteria and spores will be exhaled from the respiratory system, by way of the nose and mouth. The quantity will depend on the state of the host microbial population, which in turn depends on the state of the host. We estimate that microorganisms arising from this source will not exceed 2 mg/man/day and will be launched directly into the atmosphere during breathing, coughing, sneezing, flatulating, and talking. The number of organisms will be equivalent to about 10^{11} per cc.

RATE OF WASTE GENERATION

Co-Variances in Rate of Waste Production

In addition to the specific waste production rates given in the above section, co-variances exist whereby rate of production of any one product is affected by that of one or more others. It has been shown that the rate of sebum excretion is directly proportional to its rate of removal. The rate of sweating is due primarily to thermodynamic considerations in the maintenance of body temperature and dissipation of metabolic heat, to which, in turn, the sweat salt concentration is related. An increase in the sweat rate is followed by a greater than proportional increase in the quantity of salts deposited — and sweat has the effect of washing sebum off the epithelial surface. In turn, the temporary diminution in this sebaceous component of the surface film modifies the environment of the skin so as to allow temporary increases in the microflora populations.

Meaningful estimates of generation rates of any waste component, then, depend on averages for that component over long periods under defined physical and biotic environmental conditions. At this stage in the state of the art of manned space travel, exact estimates are impossible. Sufficient data on the diet and of individual characteristics — both in terms of physiological response and microbial content of each astronaut — will be necessary in exactly defining all wastes, their specific generation rates, and anomalies of covariances. There are also effects of weightlessness, which over prolonged periods may have profound influence in variety of cellular responses, both first and second order, of both the astronaut and his indigenous population of microorganisms and of which not even the sketchiest data are available. The anticipated lower total pressures and altered partial pressures of atmospheric gases will also profoundly affect these estimates. Until the times at which provision is made of conditions that will reproduce the defined environment, estimates such as have been given above must remain tentative, yet must allow tolerances for error of underestimates. We believe the estimates presented in Tables 6 and 7 are high average estimates.

Synopsis - Rate of Waste Generation

The specific average rates of generation of all conceivable waste products in a manned closed space vehicle are given in Table 6. The amount of materials produced as urine, feces, and insensible water (water of perspiration, respiration, and evaporation of other compounds) are included for comparison and completeness even though these are not being considered as part of this program. The total mass of wastes exclusive of feces, urine, and insensible water will amount to 12.363 gm/man/day as primary generated human wastes, which will

have a volume of about 12.341 cc/man/day. It is notable that this figure is equal to about half of the solids present in feces. The rate of generation of cabin compounds including equipment lubricants, chemicals, etc. will diminish on a per man basis with increase in crew size. However, with this category, as with others, a higher value will lead to increased load on the sanitation system. The sanitation system is designed to handle overloads thereby allowing for unforeseen accidents or other unique events.

The wastes enumerated in Table 6 can be considered in relation to both the region of the vehicle cabin and its occupants. Five general regions are: (1) the body surfaces; (2) clothing, including spongecloths; (3) the cabin atmosphere; (4) the interior cabin and equipment surfaces; and (5) specific waste collection containers. An estimate is given in Table 7 of the waste products which will be primarily deposited in these regions. The body surfaces are further broken down into face, the body proper, and the mouth (buccal cavity). These are the separate regions that will be considered in terms of hygienic techniques. The estimates are approximate and averages including some waste generations which are nonlinear processes on a daily basis.

TAPLE 6

Synopsis of Weight and Volume of Waste Product Generation From all Sources in the Closed Environment of a High Performance Manned Space Vehicle.

Values are given per man per day.

	MASS/GRAMS	VOLUME/MILLILITERS
Miscellaneous Cabin Compounds	0.700	0.720
Food Spillage	0.700	0.700
Desquamated Epithelium	3.000	2.800
Hair - Depilation Loss	0.030	0.030
- Facial - Shaving Loss	0.300	0.280
Nails	0.010	0.010
Solids in Sweat	3.000	3.000
Sebaceous Excretion - Residue	4.000	4.200
Solids in Saliva	0.010	0.010
Mucus	0.400	0.400
Seminal Fluid - Residue	0.003	0.003
Urine Spillage	0.025	0.025
Fecal Particles	0.025	0.023
Flatus as Gas		2000.0
Microorganisms	0.160	0.140
Solids in Feces	20.0	19.0
Water in Feces	100.0	100.0
Solids in Urine	70.0	66.0
Water in Urine	1400.0	1400.0
Insensible Water	1200.0	1200.0
TOTAL	2802.363	2807.341
TOTAL EXCLUDING URINE, FECES, FLATUS, AND INSENSIBLE WATER	12.363	12.341
TOTAL SOLIDS	102.363	97.341
TOTAL WATER	3700.000	3700.000
TOTAL GAS		2000.000

TABLE 7

Estimated Quantities of Waste Products Primarily Deposited in Various Niches of the Environment of a Manned Space Vehicle in Grams Per Man Per Day. + indicates probable trace.

PRODUCT	NICHE							
	EPITHELIAL SURFACE							
	FACE	BODY	MOUTH	CLOTHES[1]	ATMOSPHERE	SURFACES	CONTAINERS	TOTAL
Misc. Equipment Compounds	0.005	0.010		0.015	0.650	0.020		0.700
Food Spillage - Solids	0.040	0.060		0.050	0.550	0.050		0.700
Desquamated Epithelium[2]	0.073	2.362	0.015	0.250	0.300	+		3.000
Dipilated Hair		0.020			0.010	+		0.030
Shaver Cuttings					0.050	+	0.250	0.300
Fingernail Cuttings							0.010	0.010
Solids of Sweat[2]	0.073	2.362	0.015	0.250	0.300	+		3.000
Sebaceous Residues[2]	0.078	2.406	0.016	1.500		+		4.000
Solids of Saliva	0.004		0.002		0.004	+		0.010
Solids of Mucus	0.010			0.385	0.005	+		0.400
Solids of Seminal Fluid		0.001		0.002				0.003
Fecal Particles		0.015		0.008	0.002	+		0.025
Microorganisms[2]	0.002	0.064	0.004	.060	0.020	0.010		0.160
Flatus as Gas					2000.000 ml.			2000.000 ml.
Solids in Feces							20.000	20.000
Solids in Urine		0.010		0.015			69.975	70.000
Water in Feces							100.000	100.000
Water in Urine							1330.000	1330.000
Insensible Water					1200.000	+		1200.000
TOTAL	0.285	7.310	0.052	2.535	1.891 - Solids 1200.000 - Water 2000.000 - ml/Gas	0.080	1520.235	2732.363
							SOLIDS	102.363
							WATER	2630.000 gr.
							GAS	2000.000 ml.
							SOLIDS NOT F.F.U.	12.363 gr.

1. Including wipers
2. Assuming sufficient bathing to preclude buildups to an extent sufficient to be significantly lost by ablation.

SECTION III

SANITATION AND HYGIENE REQUIREMENTS

BACKGROUND

Sanitation and hygiene can be considered as states of a given human environment with respect to the amount of dirt present in it relative to the maintenance of health. The dirt consists of two more or less correlated phases: microorganisms and non-living particles. The significance of the dirt is twofold: it may constitute a hazard to the maintenance of human life because of its pathogenicity or toxicity, or it may effect human responses because of psychological conditioning. These two factors are clearly not mutually exclusive. As ecological concepts, sanitation refers to the "dirt level" of the gross environment, personal hygiene to the dirt level of the body itself and clothing adjacent to it. The intent of this program is to specify methods and materials compatible with aerospace operations in terms of maintaining an optimal sanitary and hygienic environment. The connotation of toxic hazards inherent in the space capsule environment is recognized but will not be specifically detailed. The requirements set forth herein apply to the gross aspects of "dirt" and not the detailed consideration of all of its manifold and interacting aspects.

The problem is a formidable one when all factors and their interactions are taken into account. For purposes of this program, the sanitary considerations involved in primary techniques of removal and treatment of urine, feces, and garbage are not considered. However, these materials must be taken into account secondarily, as it was shown above that small quantities of urine and feces will not be completely removed by primary techniques. A certain quantity of garbage in the form of miscellaneous food debris will also accidentally escape to the environment.

The first requirement of maintaining general cleanliness involves selection of chemical and physical agents necessary for removal of dirt from all parts of the human body and cabin surface environments. We have shown that these sources would contribute by far the greatest mass of material to be removed. The agents themselves must not be potentially toxic to the human occupants or be of such a nature as to accumulate to toxic levels. With the small volumes of cabin interiors this factor must be regarded as severely limiting. Even with careful testing, all errors must be on the side of safety, that is, balances between levels of cleanliness achieved by, and toxic hazards inherent to, these agents must be such as to minimize the latter. This balance in turn may relate to psychological conditioning, as would be the case with products of cosmetic value.

This section will explore the rationale of maintaining cleanliness beyond that of a closed system left to itself, discuss compatibility of desirable cleansers and disinfectants for aerospace cleanliness, and weigh the virtues of the various pathways of disposal of the encompassed wastes. Consideration will be given to the hardware required to effect the required ends in the section entitled "Integration and Future Directions."

PSYCHOLOGICAL REQUIREMENTS

The following discussion is presented as an aid in understanding the psychological aspects of sanitation and personal hygiene. Although the implications of

bathing are stressed because of the greater data available in this area, we think analogous conclusions can be applied to laundering, cabin cleaning, odors, dental hygiene, and to a lesser extent to shaving. This discussion is not mutually exclusive of the biological value of sanitation and hygiene in maintaining health. We can consider this an exposition of subjective requirements of health standards in relation to the classical techniques for maintaining them.

The comments of subjects who have participated in experiments simulating some features of space flight where normal bathing facilities were not provided indicate that there exist psychological aspects of hygenic and sanitary levels that must be considered in any complete space system. Unabated feeling of being unclean or being in an unclean environment even though pathogen-free conditions theoretically prevail throughout a space flight, may lead to resentment on the part of astronauts with consequences in at least two areas. This resentment may be reflected in behavior during a flight and, in interaction with other factors (e.g., boredom, fatigue, etc.), may decrease the effectiveness of an astronaut and even compromise his chances of survival. Second, the deleterious effects of this resentment may not end with the flight. He may eventuate a general unwillingness to volunteer for other flights.

The problem must be resolved because subjects have declared intense needs to bathe after closed environment experiences. It would be a mistake to ignore the psychological implications in which these bath needs have developed and fail to recognize that these may change enough in the future to make the aspects of the bath problem effectively disappear. A high degree of personal and surrounding cleanliness may largely be a culturally imbued need of modern, civilized, and especially western man. The derogation implied in epithets as "you stink" is well established. Anthropological sources describe primitive cultures in which bathing serves ritualistic rather than sanitary needs and is resorted to during droughts and other calamities as a means of appeasing Nature and her gods. The history of western civilization indicates that similar attitudes toward all aspects of hygiene and sanitation levels are by no means confined to primitive peoples. It seems likely that people could be trained to regard bathing as unnecessary and undesirable except as a means of mechanically removing substances that could impair health and are not readily removed by other means. That this training will not actually be carried out is not the point. Psychological changes will be incumbent upon astronauts and these will create a new "culture," a culture of astronauts, in which unnecessary bathing may not be regarded as desirable. The man who can drink treated waste products is not as likely to feel dirty in the presence of information that he is hygienically clean as is the average man.

The bath problem, therefore, may not really be as critical as it has appeared to be. It may shrink to negligible proportions in the face of other problems that the living conditions of astronauts bring into the foreground. Nevertheless, we will take the point of view that the problem of getting dirty because of not taking baths is going to exist and proceed to discuss in the following sections, the ways in which it can be eliminated or at least mitigated.

The psychological feeling of being dirty is based on perception of at least two kinds. One is the awareness of the passage of time in conjunction with the knowledge that no satisfactory cleansing action has been taken during the interval. Another is the direct sensation of "dirt" and dirt-producing body products on the surface of the body, e.g., grease, sweat, etc. No one would deny that

the latter group of sensations is directly related to the feeling of being dirty, but the psychological role of the former is generally underestimated. However, it is precisely this factor that must be considered most carefully in the critical evaluation of any scheme that purports to solve the bath problem, primarily because of the strictness with which humans are prone to interpret the phase "satisfactory cleansing action."

The direct approach to the cleanliness problem would be to provide adequate bathing facilities for the astronaut. This would require an artificial gravitational field and would thereby impose sufficient constraints to rule it out as a solution. Nevertheless, only this approach seems likely to guarantee elimination of all psychological sensations of being dirty. Using a bath suit in the aerospace situation can be expected to remove accumulated dirt products from the surface of the astronaut's body. However, the human reacts peculiarly to unusual bathing situations and may well not regard a bath suit as a "satisfactory cleansing action." Campers, for example, who have bathed regularly in streams and lakes, are generally anxious to take a "real" bath or shower on returning to their homes because they "do not feel clean" until they do. The case of troop transports in which salt water showers are available for bathing is not exactly comparable because of the salt residue left on the skin. Nevertheless, it again points up the fact that "unsatisfactory cleansing experiences" involve more than meets the eye. Criticisms levelled against sponge baths are on these grounds also, even though a careful sponge bath may provide cleaning equivalent to a regular bath or shower. The experience of sponge bathing probably will not satisfy the need for cleanliness because it differs too much from the accepted method of bathing or cleansing.

It seems advisable to perform tests of the effectiveness of training in conjunction with any evaluations of bath suits and the like. One way in which training might be supplemented would be by demonstrating the cleanliness of a space cabin in terms of its measured effect on personal cleanliness. If subjects' hygienic states were measured after different periods of confinement in these dirt free surroundings and under "normal" conditions, a table of equivalents could be made and would serve as a vivid demonstration of the meaning of "dirt free." If one week in space is the dirt equivalent of one day on earth, the astronaut who has been away for two months may very well feel no dirtier than the traveler in other countries than the United States who is forced to sponge bathe except for a weekly trip to a public bath.

BIOLOGICAL REQUIREMENTS

In addition to, if not an adaptive basis of, the subjective feelings of cleanliness, there is a real necessity in maintaining any habitation relatively dirt free. The biological validity of this conclusion has two aspects: toxicity, including allergy, from materials that are allowed to accumulate; and pathogenicity from a number of microorganisms that could flourish on available substrates in the absence of attempts of disinfection or removal.

However, this biological requirement of a dirt-free environment is not absolute, but relative. The apparent paradox is in part a result of phenomena associated with the mechanisms of immunity. There is conclusive evidence indicating that the immune state is maintained through periodic challenges by extraneous antigens. Thus, the presence of a finite, yet very low level, of such antigens may be beneficial.

Most non-living foreign matter at some critical concentration has deleterious effects on the physiological machinery of the body. These are manifested in three ways: by intoxication, by hypersensitivity, or by mechanical irritations. Intoxication is the noxious physiological consequence of a chemical compound that interferes with the proper function of enzyme systems. The agents that induce intoxication are called toxicants or poisons and include a vast and diverse group of compounds of both organic and inorganic origin.

Hypersensitivity, on the other hand, is associated with the antibody -- antigen reaction. It differs diametrically from the immune state, however, in that following an initial challenge by a foreign substance its second challenge leads to unpleasant reactions. The most familiar reaction, allergy, is likely to be the only form of hypersensitivity consequential in aerospace missions. Endogenous asthma of the upper respiratory tract and contact dermatitis could occur in the presence of unusual compounds that may be given off in closed systems. Food allergies could also occur. The probabilities of allergy causing compounds in the closed environment during aerospace missions may be highly significant, particularly in low atmospheric pressure regions.

Mechanical irritation is imparted by any particulate matter, as solid dusts or liquid aerosols, of such dimensions as to insure their retention in the respiratory system. Often a chemical effect is associated with mechanical irritants. In general, large particles are removed in the nasal area while small ones are not retained at all. Those particles not exhaled or impinged on the epithelial surfaces of the lungs are moved into the gastrointestinal tract. This is brought about by the removal mechanism of the nasopharyngeal mucosa.

A certain amount of dirt will consist of living particles — bacteria, fungi, viruses, etc. — which could have pathogenic consequences. The opportunistic varieties of microorganisms, such as the Streptococci and Staphylococci, universally present in the nasopharyngeal area as benign saprophytes, are harmless until such occasions arise as to permit their rapid proliferation and consequent deleterious effects. An environment containing quantities of organic debris will allow such forms to increase in numbers and become hazardous.

The safest conclusion with regard to dirt, taking all of the above points into consideration, would be to provide a means of completely removing all possible debris from the environment. Coordinate with this goal would be maintenance of body resistance through maximization of physiological well being during flight conditions. This will be accomplished by proper nutrition, avoidance of fatigue, minimization of probability of epidermal punctures, etc. The considerations of lowered humoral immunity due to lack of challenges by specific terrestrial antigens will probably be consequential only after long missions. Capsule environment — surfaces and atmosphere — must be kept scrupulously clean. The role of disinfection should, therefore, preferably be accomplished by removal and not chemically, as disinfectants could themselves provide toxicological problems. They may also not do the job well.

PREFLIGHT CONSIDERATIONS

Preflight conditioning of both man and machine must be considered. The presence of dirt of all sorts is obviously anathema, but its removal can only be guaranteed for the machine. The policy of avoiding materials that give off toxic compounds,

vapors, or dusts under aerospace conditions should be rigorously dictated. The interior of the vehicle should also be sterilized to minimize the probability of including living particles that are, or may become, infectious. The rigor demanded of such techniques is related to projected flight durations. If the minimum incubation period of any probable infectious disease is 2 days, flight durations of that or longer periods would demand maximum cleanliness. For less than 2-day missions, inflight performance would not be affected by endogenous sources. Free particulate material should be removed as completely as is practically possible.

Although astronauts should be thoroughly clean before flight, there is a residual microbial population that cannot be efficiently removed. In addition, there is the constant production of wastes from many sources. In spite of these unavoidable materials, procedures will have to be prescribed to bring them to a steady state of predictable quality and rate of production. Quarantine under approximate flight conditions would serve this purpose. Thus, the presence of potential pathogens have a high probability of becoming unmasked, providing a sufficient quarantine period to permit their incubation and manifestation. This period may also reveal allergic reactions which escape earlier detection. Under constant conditions, the equilibria of these factors should lend greater confidence to minimization of hazards from organic sources during the actual flight. In spite of such added hardships to a long mission, overprecaution is more desirable than jeopardy from unknowns. If new and comprehensive information on microbial/human ecology becomes available before such flights are technically feasible, these preflight requirements may be completely modified. There are no such data currently available.

CLEANSERS AND DISINFECTANTS

A vast number of chemical agents are available for use in cleaning and disinfecting man and machine. Selection of the compounds or combinations of compounds for these purposes is critical. Optimally, something must be used that can combine maximum cleaning action, including removal of both living and non-living material, and a minimum of toxic hazard. The effectiveness of the compounds will be related to method of application and use.

We believe it most useful to consider individual functions requiring cleansers and inquire into the rationale of selection for each. Cleansers are required for the following separate operations:

1. Dental Hygiene
2. Whole Body Bathing
3. Hand and Face Cleaning
4. Laundering
5. Cabin Cleaning.

Indentical compounds will be used for all purposes except dental hygiene. Only their method of use will differ. The materials recommended are tentative suggestions for the simplest system conceivable at this time. Advances in technology could lead to considerable modification.

Dental Hygiene

The major problem of dental hygiene during aerospace missions will be stimulation of the periodontic area (gums). The problem of decay will be minor, particularly in flight durations of less than six months, because of dietary adjustments that can minimize propulation growth of decay organisms. Mechanical removal of detained food particles and exfoliated epidermal cells will be aided by any cleanser with abrasive and surface acting detergent qualities. To avoid methodological complexity, the components of the dental cleanser should be completely nontoxic and ingestable.

Through the courtesy of Dr. Frederick A. Shillito, we have obtained two formulations that fulfill these requirements. These were suggested by Prof. R. A. Kuever. Both are in the form of a paste, a physical consistency ideal for use under weightlessness.

The two formulations differ in that one contains 0.5% Sodium Lauryl Sulfate as a detergent. Both are identical in other ingredients, essentially consisting of calcium pyrophosphate suspended in tragacanth aqueous glycerine base. Sodium benzoate (0.25%) is added as a preservative, and a trace of methyl salicylate for flavor. The detergent paste would doubtless be preferred, but either would do in fulfilling the requirements. Both leave a pleasant after taste in the mouth, and considering the conventional method of application which will be used in aerospace, should be psychologically fulfilling. Long term ingestion should have no deleterious effects. The ingredients which might present problems are the preservative, detergents and flavoring. All are far below toxic values for ingestion even on an additive basis considering a sixty day flight. They are all specified in the U.S. Pharmacopiea.

Body Cleansers

The selection of a compound for hand and face cleaning and for whole body bathing is the most critical aspect of personal hygiene in the small volumes of spacecraft. The considerations bearing on this selection include (1) cleaning efficiency, (2) disinfection efficiency, (3) toxicity in the broadest sense, and (4) relation to mode of disposal.

Since the cleaning compound will be in an aqueous solution, it may be possible to be recovered and reused. In fact, the nature of the effluent solution from bathing is such that, assuming adequate filtration of microorganisms and colloids, only the cleanser will limit direct ingestion. The potential of recycling the bath waters through the human metabolic machinery, rather than the water recovery system, would permit a sufficient power savings to justify its serious considerations. Implementation of this idea results in a water handling system for sanitation and hygiene that can be self-contained.

Cleansers are defined as surface acting, detergent compounds. As such they are capable of removing liquid and solid soils from surfaces. Specifically, detergents refer to surfactant compounds that lower surface tension of soils and dirt so as to place them in an aqueous suspension and wash them away before they can be redeposited on the cleaned surface. This definition implies more than surfactant qualities, so detergents and surface acting compounds are not synonymous.

Detergents are usually classed into three groups, all of which have been considered for employment in personal hygiene and sanitation. These are anionic detergents, cationic detergents, and nonionic detergents, depending on the nature of their dissociation in solution. A brief summary of their characteristics follows:

Anionic Detergents - These compounds embody two main groups; soaps, and the alkyl sulfates. The latter comprise the common synthetic household detergents. The surfactant qualities of the synthetics are well known and are perhaps most outstanding of all detergents on a molar basis. Some are also bacteriostatic. These act only on gram-positive bacteria, however. They are prone to cause foaming in low concentrations (1 ppm) and also may induce contact allergies with prolonged use.

Soaps have very limited antimicrobial action, but are excellent detergents. As with all detergents, their surfactant qualities in removing soils, particularily fats and greases, also mechanically remove microbes which are embedded in these soils. Since it is the soils which provide substrates for microbial growth, this mechanical action also serves to greatly reduce their populations. When the surface of the skin is washed with soap then, the microbial populations are considerably reduced. There is no residual bacteriocidal effect, however. Combination of bacteriocides with soaps remedy this situation and the practice is commercially alluded to for this effect. Hexachlorophene is the usual additive.

Pure soaps are usually potassium or sodium salts of fatty acids, although the metal can be substituted by various amines. They are perhaps the least toxic of all detergents, their components being common metabolites of cellular respiration.

Cationic Detergents - These compounds are generally quarternary amines, and are known in a large number of different formulas. They are all good general bactericides and fungicides. They are not good detergents, however, a property compensated for by combining them with some compound, that is, usually a nonionic detergent. Such combinations produce excellent bactericide detergents in low concentration.

The cationics are of questionable value, however, from several toxicological considerations. Although they are relatively nontoxic in low concentration, they are not uncommonly allergenic. They are also known to strongly bind to protein, can cause irreversible damage to the eye, and when taken internally occupy sites on nerves, thereby blocking the formulation of acetylcholine.

Nonionic Detergents - These generally include polyethers and polyglycerol esters.

The nonionic detergents are generally good surfactants, but poor germicidals. There are a considerable number of formulas, most of which combine compounds that may constitute toxic hazards.

Of the enormous number of detergents that can be employed, soaps appear to offer the best possibilities as cleansers in the aerospace environment. A pure soap is mandatory, preferably sodium or potassium oleate or palmitate. These are soft

soaps, and would go into solution easily if hot water is not available. Tallow soaps, which generally have high titers of inedible fats, as stearate, should be avoided. Only the purest compound should be employed. Any ingredients, such as perfumes and disinfectants, should be precluded. Since there appear to be no brands of soap on the market that meets these qualifications, a special soap will have to be synthesized for this program. Frequent bathing will be used to accommodate for the limited bacteriocidal action and lack of residual effect.

The same soap can be effectively employed in all aspects of sanitation and hygiene. The requirements of minimization of the microbial count of the total cabin environment will be effected by keeping the soil down. This will include adequate cabin cleaning and laundering as well as personal cleanliness. The minimization of the microbial population will also rely on an air-conditioning system capable of maintaining a moderately low humidity and of removing substantially all organic particles from the air. A dry atmosphere alone kills most bacteria and fungi with time.

The utility of bactericidal or fungicidal compounds will not answer all the problems relating to hygiene. In addition to microorganisms, there are the hazards inherent in viruses, rickettsias, and antigenic proteins. Although such biological particles cannot reproduce on extracellular substrates, they will be present and can be negated only by mechanical removal. This provides an argument against methods of disinfection and for implementation of removal techniques. Since soaps are effective detergents and offer the minimum of toxic hazard, no better cleanser is apparent at this time.

GERMICIDAL ADJUNCTS

Although the use of germicidal agents cannot be recommended for any part of inflight maintenance of sanitation and personal hygiene, they may have a limited role as preflight finishing agents. In this role their quantification could be accurately determined and their resultant toxic hazard assessed and predicted. As such, two specific functions can be investigated. These are treatment of all cabin and component surfaces, and treatment of clothing. Two products have been reviewed for these purposes, others may be available at present or in the near future which possess similar attributes.

An aerosol germicidal spray, SBT-12, is a commercially available product developed for imparting a lasting antiseptic quality to hard surfaces. Its major use is as a hospital germicide. The active ingredient is 3, 4^{1}, 5 tribromosalicylanilide. Tests with the compound showed it to be germicidal to a variety of common bacteria, including pathogens. In addition, it appeared fair to excellent in preventing growth of several indicator fungi. In the latter case, the action was effective for three weeks. Toxicity data showed no pathological effects from chronic inhalation by rats and only moderate erythema and hyperemia when sprayed directly into the eyes of rabbits. Patch tests on humans were negative in spite of substantial exposures. Treatment of all cabin surfaces with this or a similar material before flight would appear to serve as an important adjunct in minimizing microbial multiplication. Caution need be exercised in regard to toxic implications only under aerospace conditions. These implications will demand specific test programs in simulated cabin environments.

The greatest numbers of microorganisms that will be liberated to the atmosphere will arise primarily from the skin. The majority of these are their accompanied

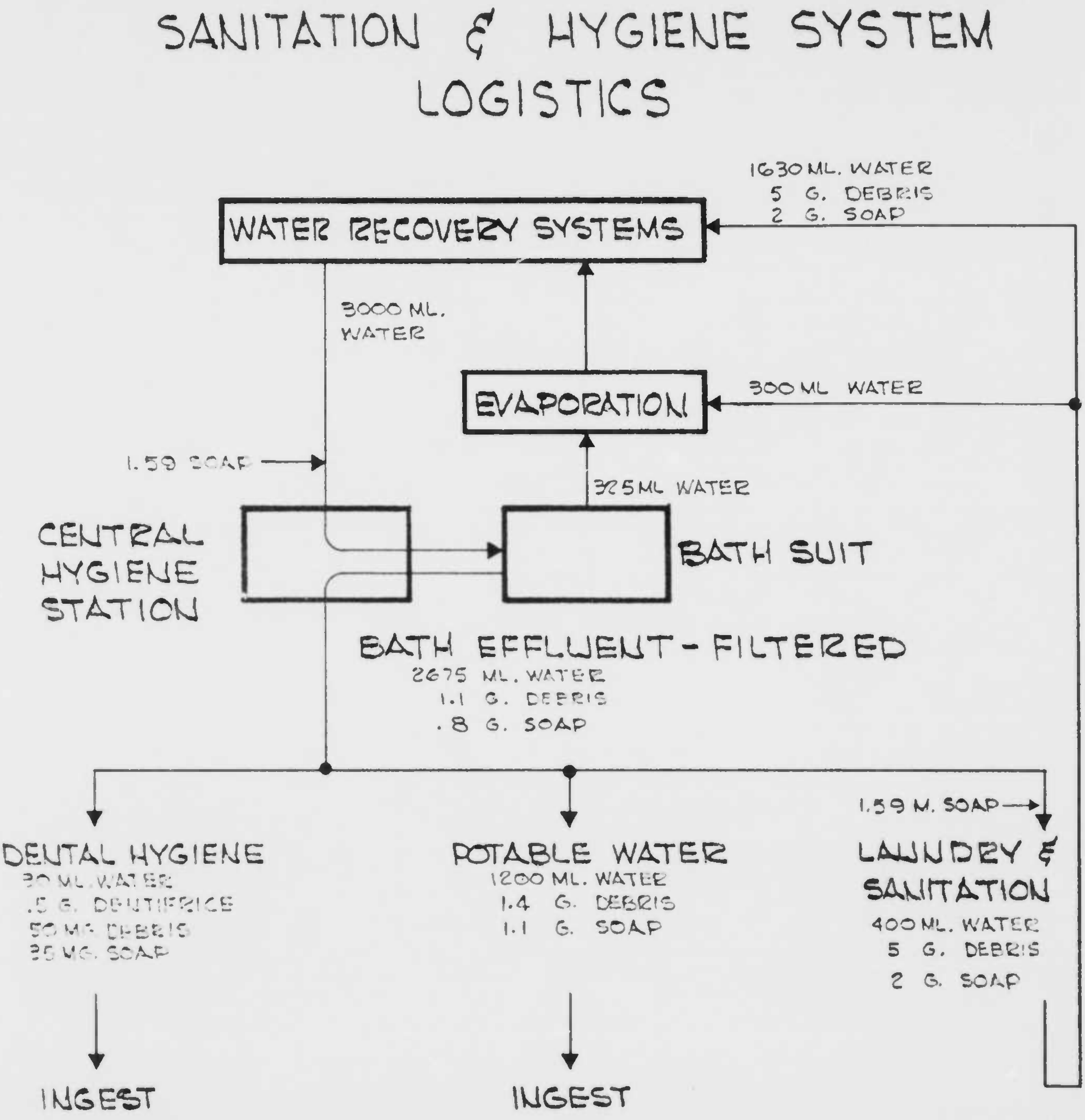

Figure 1. Daily Per Man Rates: Water, Soap, and Waste Turnover

substrates, in the form of fine particles of skin debris, will be deposited on the clothing adjacent to the body. The rationale of laundry requirements is aimed toward reducing the populations in the clothing. As an adjunct, the combination of a germicidal compound into the clothing fabric would be a powerful agent in precluding growth. The primary requirement of such a compound would be its retention through a number of washings. The "cyana" process, employing aerotex purifying agent No. 1 appears able to fulfill this requirement.

The "cyana" process is a technique developed in the resin finishing of fabrics. In this process an antibiotic, neomycin, is mixed in a resin and locked on the fabric. The fabric can stand up to 25 washings without effective loss of the germicidal action. Patch tests of treated fabric showed no evidence of irritation or sensitization, even with repeated challenges. The toxicological effects of neomycin are well documented. If absorbed in sufficient quantities, it acts as a neurotoxin. There appears to be little hazard, via the oral portal, as there is apparently no significant absorbtion. Before use in space vehicles, more precise testing of potential toxicological implications will be necessary. The utilization of such a compound has an added value in decreasing body odor production by virtue of control of the microorganisms producing such odors by their metabolic activities.

SANITATION AND PERSONAL HYGIENE WASTES LOGISTICS

Figure 1 gives an estimate of the logistics of sanitation and personal hygiene operations on a per man day basis. A glance shows that the most abundent material involved is water. Water acts as a solvent for the soap detergent and as a carrier of soap and debris following all cleaning operations. According to these estimates, 3000 ml of water will be required for each man each day, of which about 625 ml will be lost by evaporation. The reasons for this evaporation loss are given in the next section. This water will be recovered by condensation in the heat exchanger required for maintaining atmospheric habitability, which, along with that recovered from insensible perspiration and respiration, will be available again for other purposes.

Of the remaining 2375 ml of water, 1630 ml will be represented as the effluent of laundry and sanitation. This effluent will have a high soil and soap content and should be recovered by the system designed for urine water reclaimation. The urine recovery system should be sized accordingly. The residuum 2675 ml, which is the effluent following a single whole body bath, will contain no more than 0.8 gm soap and about 1.1 gm debris. The greatest fraction of the debris expected will be particles of sizes greater than 1 μ and dissolved salts. A significant power savings would be effected if this effluent could be reutilized without processing directly through the urine recovery system. We propose selection of one of three alternate pathways of effluent reutilization. The primary requirement of any mode of reutilization is filtration.

The first pathway, simple filtration through a 5 μ depth filter will remove almost all bacteria and detain a certain proportion of smaller particles - viruses and large proteins. The VF millipore filter or its equivalent could be added downstream in order to detain the bulk of the latter debris. Although soap, salts, and all substances in solution will pass the filter, the processed effluent could be reused several times for bathing. Its total solids content is estimated at about 0.15%, which will be preponderantly salts and soap. This solids concentration is less than the maximum solids content acceptable to USPH standards for drinking water under emergency conditions.

Thus, although the solids concentration will build up additively with each reuse, three or four passes can be achieved without demanding complete solids extraction. A hygienically limiting factor in reuse of the bath effluent for additional bathing would be the substantial soap residue. Soaps would partially dissociate into fatty acids which could be used in supplying a carbon source to support limited bacterial growth. Since there is no active disinfecting principle in the effluent, bacterial buildup would be limited only by dilution with new water.

The second pathway would involve ingestion of the 2675 ml by the vehicle occupants. Water provided through this pathway would be reclaimed, but by human metabolism rather than other water recovery systems. In the overall water cycle of the vehicle, however, this amount would ultimately be excreted as perspiration and urine. At such time, it would be recovered by other systems. A large energy savings would be effected by this pathway.

A major requirement for enabling ingestion will be removal of the soap. Concentrations of about 0.1%, which are recommended for reasons of adequate detergency, would be emetic in this quantity. It should be relatively simple, however, to remove most of this soap from solution by a choice of one of several ways:

1. Ion exchange resins (Reference 1).
2. Addition of mineral acid to convert soap to insoluable fatty acid, removable by filtration*.
3. Addition of calcium salts to precipitate soap as insoluable calcium salts of fatty acid, removable by filtration**.

The second possibility is the least desirable because of the inherent dangers in handling a mineral acid such as HCl. The use of calcium salts, as $CaCl_2$ or CA-Acetate, would produce a fatty acid salt precipitate that may not be edible, although easy to remove by filtration of a coarse floc. Both approaches have the unusual property of permitting regeneration of soap through re-saponification by treatment with an appropriate hydroxide. An inherent disadvantage is the requirement of a considerable filtration capacity.

The use of ion exchange resins, such as Duolite A-7 (Reference 1), would be operationally most foolproof. Columns could be sized to accommodate the appropriate load anticipated for specific mission durations. Although the approach appears reasonable at this time, further research will be required to determine if this procedure is in fact ultimately economically feasible. The unknown which must be determined is the through-put rate needed to adequately remove the soap anion. There will also be a problem of competition of other anions for sites on the resins.

The third possible pathway into which the 2675 ml can be shunted would be directly back to the hygiene water reservoir following soap removal. This would be likely only in case of objections to ingestion for psychological reasons. The number of times this could be accomplished would be limited by salt accumulation.

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* Owen, Carter 1961, Personal Communication
** Frantz, A.J. 1960 and Owen, Carter 1961, Personal Communication

Before finally selecting a pathway, integration with other parameters will be required. These include penalties of weight and power. It may be that the 2675 ml can be more economically processed by urine recovery systems when all these factors are considered. The decision involves rate/power ratios of the various alternatives, as well as the desirability of a back-up water source.

SECTION IV

SANITATION AND PERSONAL HYGIENE SYSTEM

REQUIREMENTS

The general operating conditions and system requirements have been stated in the Introduction. The prototype system to fulfill these requirements will be described in this section. Many modifications will doubtless be effected before it can be utilized for actual missions. The immediate limitations are concerned with integration of this system with other systems of life support. This prototype cannot operate independent of these other systems unless there is considerable component duplication. As an example, there is no provision for permanent water storage. It has been assumed replacement water for that lost through usage will be made available from some main reservoir. There is also no provision for air-water separation following bathing procedures. Separators for this purpose are clearly required elsewhere. Other duplicate components have been likewise eliminated in our design. They will be specifically indicated as apropos in the following discussion.

With the exceptions of integrated functions required from these other components, this prototype system will fulfill its requirements and operate under the specified aerospace conditions. Its efficiency in effecting biological and psychological requirements will remain unknown for the many reasons stated in this report.

Table 8 gives a list of all components required in the system. The personal gear are enumerated for one crewman and should be multiplied according to the selected crew size. The soap tablets, which are expendables in both the shared and individual categories, will be required at the rate of three a day in each. The toothpaste load can be sized to fit any flight duration.

CENTRAL HYGIENE STATION

Scope

The central hygiene station lies at the core of the sanitation and hygiene system. It consists of the apparatus that circulates all the water and effluents required of the system, it serves as the site for performing hygienic tasks, and is the storage locker for all sanitation and hygiene material. The specific direct functions of the station can be enumerated as follows:

1. Supply and exhaust of fluids required in treating and cleaning the sanitation gear. This gear consists of sponges for cleaning all surfaces.
2. Repository for the net that will be used to retrieve any large particles.
3. Repository for all personal individual hygiene gear including:
   a. Laundry Bag
   b. Tooth Brush
   c. Facial Spongecloths & Bag
   d. Towel Spongecloth
   e. Dry Shaver & Spare Blade.

4. Power-supply outlet and holder for the crew shaver. There will also be a crew nailclipper.

5. Source, supply, heater, and reservoir for water and effluents for:
   a. Whole Body Bathing
   b. Partial Bathing (Hands and Face)
   c. Dental Hygiene Operations
   d. Personal Laundering
   e. Cabin Sanitation.

6. Repository for shared gear and sanitation materials.

Each of these functions will be elaborated under the defined categories of sanitation and hygiene activities discussed in this section.

Design

The station configuration is presented in Figures 2a, b, and c. These are photographs of the full-scale operating prototype. The station is designed to operate under the conditions specified, of which the most critical requirements are operation under weightless conditions and minimum power requirements.

The station can be mounted on any bulkhead convenient to water, power, air intakes, and waste disposal line. The mount will be at a level to take advantage of human engineering research embodied in the relationship of height of the control panel to height of the operator's hands and eyes. (See Figures 2b and 2c).

The station is structurally divisable into two main parts: a portion of one-half cubic foot which comprises the fluid control and a portion concerned with material storage. The latter has several ancillary features engineered to maximize versatility and function. Station inputs must include fresh water, 115 volt A. C. power; output must include a line to water recovery. All input and exhaust facilities are through the left side of the station. The body of the station is constructed of aluminum.

Fluid control is effected by a plumbing system, including pump and reservoir, controlled by a pair of valves. A 5μ depth filter is placed on the pump line so all fluids moved will be filtered. The filter cartridge is replaceable. Versatility of the entire plumbing component is enhanced by a direct fresh water outlet, separate from the waste outlet. Both outlets are accessible by quick disconnects. Use of the station as a direct fresh water point assumes pressure on the fresh water line. The control valve placement to flow relationships on the control panel have been designed such that the valve handles point to the actual outlet on the panel as well as to the written word. For example, when the "Water From" valve is switched to "Wash" the valve handle actually points to the wash water outlet on the panel. The left to right placement accounts for the natural tendency to envisage flow in that direction. Therefore, the left valve indicates where the fluid originates and the right, where the fluid is to go. The valving is mechnaically interlocked such that no fresh water may be lost by flowing directly to the waste line. The panel is recessed to prevent interference with the valves, switches, and disconnects.

The reservoir has a 3-liter capacity. It consists of a bellows designed to lie flat during acceleration, and is completely enclosed in the station for protection. It serves not only for interim fluid storage, but as a metering device to precisely limit the amount of water admitted to the suit.

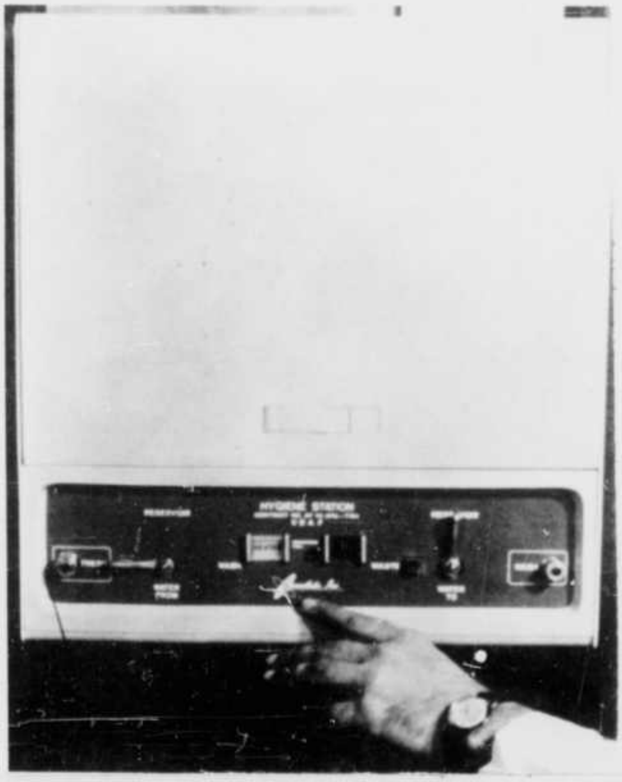
TABLE 8

SANITATION AND HYGIENE SYSTEM COMPONENTS LIST

QUANTITY	DESCRIPTION
	Shared Crew Gear
1	Central Hygiene Station
1	Bath Suit
1	Bath Suit Attachment Hose
1	Laundry Bag - Sanitation
21	500 mg Soap Tablets (7 day supply)
4	9 x 9 x 1/8 Inch Cellulose Spongecloths
1	Electric Shaver & Cord
1	Net - Large Particles Collection
1	Nailclipper
1	Soap Tablet Container
1	Toothpaste in Tube
	Personal Gear
1	Toothbrush
1	8 x 24 x 1/16 Inch Cellulose Spongecloth
2	7 x 9 x 1/8 Inch Cellulose Spongecloths
1	Dry Shaver
1	Dry Shaver Replacement Blade
1	Laundry Bag
2	8 x 12 x 1/8 Inch Cellulose Spongecloths
1	Plastic Bag - Spongecloth Container

2a. BATHSUIT CONNECTED

2b. HYGIENE STATION OPEN



2c. STATION CLOSED

FIGURES 2a, b, c

STATION CONFIGURATION

A thermostatically controlled heater unit is wrapped around the reservoir to permit warming water before bathing. The thermostat is preset to a temperature of 104°F.

Storage space is provided above the fluid control panel. Storage for the individual gear consists of a section divided into six vertical chambers. Each will carry the personal hygiene material assigned to each man, assuming a six-man crew. The vertical sections are each subdivided into four horizontal chambers. These will carry personal gear listed in Table 8.

A common storage space for all shared gear has been provided across the top of the station. From left to right it is divided into three sections in which the following will be carried: (1) the shared electric razor with cord and plug-in, and nail clipper; (2) the entire soap tablet and toothpaste supply; and (3) the sanitation laundry bag, particle collecting net, bathsuit connection hose, and sanitation sponges. The bath suit will be stored outside of the station.

Some form of air ducting must be provided to dry wet materials that are placed in these storage compartments. Lacking information on the configuration and placement of such ducting, the prototype has not provided for this necessity. We suggest a 1-inch slot be opened across the third chamber of the upper storage compartment to act as an air exhaust. This will also act to pull shavings away from this site when the cover is raised. Air intakes to the storage compartments can be achieved by an opening through the lower right panel of the individual storage compartment. Additional slotting through the vertical and horizontal compartmentation will produce the required air circulation.

Capability and Integration

The capability of the station will include fulfilling those functions called out previously in this report. The technical modes of operation of the station are given in the various categories of sanitation and hygiene specifically described in the remainder of this study. The capacity of the station is sufficient to perform as designed for the maximum crew and mission duration. All functions, however, must be performed in series. Preliminary considerations indicate each man will spend an average of about 40 minutes per day fulfilling his sanitation and hygiene duties as defined by this program. A considerable part of this time will be consumed operating under the stress of weightlessness - a consideration which may result in this estimate being optimistic.

The station, serving as a fluid control apparatus, will be required to handle 3000 ml of water per man per day. The pump we used can move this water and effluents at about 1 liter per minute in order that control can be achieved for laundering procedures. This slow rate of flow will permit accurate coordination of the amount of solution flowing into these devices by timing the pump. More rapid flow would increase capacity, but decrease control. Where compromise is required, we lean to greater control.

Integration of the station with respect to water input, waste output, and air flow has been outlined. We have made several assumptions regarding these. Although the validity of the assumptions is by no means clear, we hope they will prove useful to workers considering mechanically integrating these systems in the future. We have assumed that the fresh water source will provide distilled

water. We also assume, for a portion of the operation, that this water will be under pressure. The waste storage facility and treatment facilities must also be sized for the output load.

In order to achieve water-air separation following all operations under weightless conditions, some separating device will be required. Since this will lie external to the central hygiene station for other purposes a few changes in the hydraulic flow scheme must be made. The simplest solution would involve a line and valve that would shunt fluids from waste through whatever separator is finally used. The fluid would be returned to the reservoir under pressure from the separator. In this manner effluent withdrawn from the suit following bathing can be directly separated from entrapped air and returned to the station reservoir.

Power for the prototype has been specified as 117-v, 60-cycle current. Other power specification will require alteration of the razor, pump, heater, and thermostat.

SANITATION

Scope

Under the rubric sanitation are those techniques required to keep the environment of a vehicle interior clean and free from noxious odors. The techniques will be implemented by using the central hygiene station, soap, spongecloths, a special net, and a cleaning bag we refer to as the laundry bag - sanitation. Water will be provided as a cleanser in combination with the soap.

Cabin Cleaning

Cabin surface cleaning will be effected by daily manual wiping of all surfaces with a soap impregnated spongecloth. We recommend using a 9 x 9 x 1/8 inch cellulose spongecloth for all surface cleaning. Four such cloths are provided. The final size and number of cloths will depend on the area and nature of the surfaces to be cleaned and on the durability of products available at the time of actual flights.

Two general types of sponges are classically employed in surface cleaning, vacuum and capillary action sponges. The latter type are best suited for space operations since they retain fluids in small tortuosities by capillarity rather than in large cavities. Thus at zero G they will retain liquids in any attitude, and equally well absorb surface materials. The spongecloths are placed in the upper storage chamber of the central hygiene station. For use they will be placed into the sanitation laundry bag where 0.5 grams of soap will be added and about 100 ml water will be pumped in. The amount must be gauged by tactile and visual coordination. This water will be obtained from the reservoir and will be present, as well as bathing debris which has passed filtration. Such a procedure will conserve water, as well as some soap.

The laundry bag configuration is shown in Figure 3. It was fabricated of mylar-nylon laminate and spongecloth in a similar pattern to that used for the bath suit. Access to the bag is through a watertight zipper closure. When not in operation, the bag can be rolled into a volume of about 4 cubic inches.

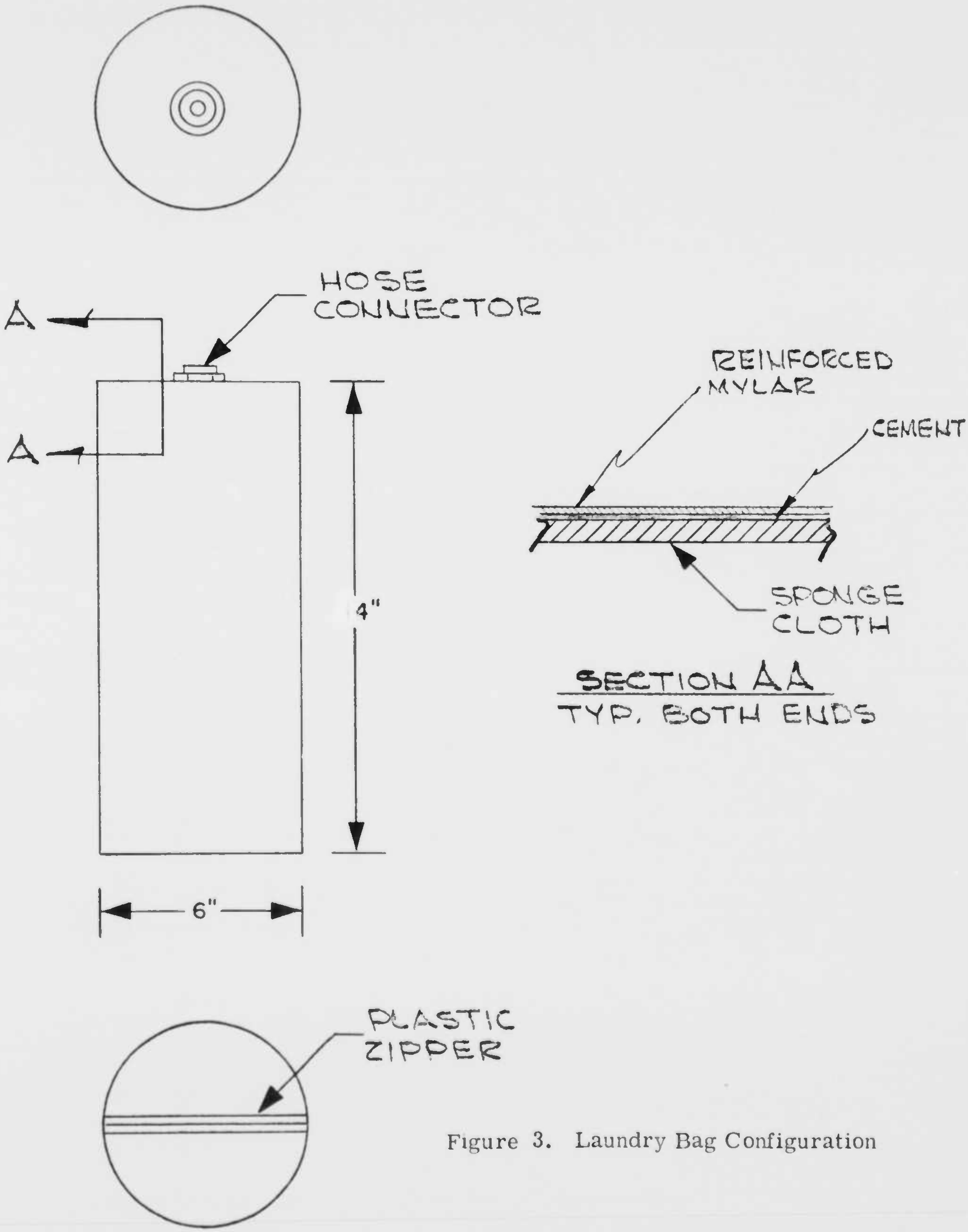


Figure 3. Laundry Bag Configuration

One dry spongecloth of 9 x 9 x 1/8 inch dimension is capable of absorbing about 100 ml water. Half squeezed it holds about 50 ml. In tests we have conducted on painted surfaces, about 3 cc is given up per 10 sq. ft. of surface by a wetted spongecloth. Assuming a surface equivalence of 500 sq. ft. for each man, with daily cleanings, 150 cc of cleaning solution will be deposited per man per day on the surfaces. The aqueous phase will evaporate, leaving a micro-film of soap on the surface. During the daily cleaning operations the film will be replaced, accumulated debris removed onto the surface of the sponge, and partial disinfection thereby achieved.

The material accumulated in this manner on the sponge will contain a variety of inorganic and organic debris, estimated at about 5 grams per man per day in addition to soap concentrations of about 2 grams in 150 ml, which can be removed from the sponges by physically squeezing them and pumping out the effluent. This load of solids will be of no further use. At the conclusion of surface cleaning, the sponge will be placed back into the sanitation laundry bag. The bag will be attached to the wash connector of the central hygiene station, the control set to waste. Following manual agitation to loosen dirt, the pump will evacuate the effluent and shunt it to the water recovery system. One rinsing will follow, drawing on the reservoir supply. The spongecloth will be removed from the bag and placed back in the storage compartment of the station for drying.

Operationally, several men may either simultaneously or serially clean the surfaces, or the crew can rotate this chore. A daily cleaning schedule is provisional and open to modification pending trial and data gathering in space vehicle simulators.

Large Particle Removal

Since accidents do happen, provision must be made to retrieve large particles from the cabin atmosphere that are of a nature as to fracture or crumble if hand seized. Various foodstuffs would fall into this category. The most reliable method of removing these substances would be with a net, similar to insect or fish landing nets. The Spacelabs' solution incorporates a collapsible net which folds to a volume of about 4 cubic inches. When expanded, it has a handle 5 inches long and 1 inch in diameter with a net diameter of 12 inches. Particles "dropped" into the atmosphere will be recovered by swinging the net to intercept them in the air. With the large net diameter this action will be accomplished with speed and precision. Deft folding of the net bag will entrap them. The fate of the particle so captured depends on its nature. If useable food, it can be directly ingested. Since the air of the cabin must be highly purified, there should be no objection to doing this. In cases where there is an objection, such as with foodstuffs as wet masticates, the residue can be directly placed into the garbage disposal system. When the net becomes soiled because of capture of materials with wet consistency, the net bag can be easily removed and laundered in the sanitation bag in order to minimize microbial growth. To engender maximum efficiency the net should be positioned adjacent to the kitchen functions, although space is provided in the station.

Air Filtration and Sterilization

Removal of small inorganic, organic, and microbial particles and molecules capable of imparting noxious odor or toxic hazards will demand sophisticated air conditioning. There are two aspects of the problem: air filtration and/or air sterilization and detoxication. A collection of a minimum of 2 grams of

miscellaneous solids and 2 liters of flatus as gas will be discharged into the atmosphere daily. These will range in particle size from food crumbs in the microscopic range to hydrogen gas molecules. Some of the particles will consist of a menagerie of viruses, bacteria, fungal spores and hyphae, yeasts, etc. Currently available depth filters can be incorporated into duct intakes for removal of particles down to about the 5 μ size. Further study will be required, however, to optimize these filters in terms of relating air flow, air volume, particle frequency, and particle size. The ideal filter would be a type sufficient to function without replacement for the total mission duration. Weight savings conceivably could be gained on the other hand by provision of filter cleaning facilities. Configuration would depend, too, on sterilization facilities. For instance, a thin surface trapping 2 μ filter would permit UV radiation to be used for killing all trapped microorganisms. A back-up filter would catch all viruses and large proteins.

Effective detoxication of noxious odors could be accomplished using powerful oxidants. An eminent candidate would be K_2O_4, potassium superoxide, which has been widely proposed for use in respiratory gas exchange(Reference 2). If such gas exchange systems attain operational feasibility, they may prove sufficient for odor removal as well. It is noteworthy that superoxides are also powerful bactericides and viricides.

Decisions to dictate optimum hardware depend upon further studies of cabin ecology and qualification of related systems. We must know more about the materials given off in closed systems over extended periods of time. We must also know the extent to which other systems can be integrated into air detoxication.

PERSONAL HYGIENE

Immersion Bathing

The problem of bathing involves perhaps the most complex materials and techniques of the hygiene system. The evolution of a central hygiene station to handle the required fluids was largely necessitated by the bathing function. Effective bathing in the weightless environment of space operations requires an enclosure to contain a cleaning solution about the bather. For short duration flights of less than a week, simple sponge baths would probably be effective. However, longer flights dictate a home-like bath for psychological desirability as well as the probable more exacting demand of removing debris and its attendant microbial populations for biological reasons.

The most effective solution to both problems for long duration missions lies in a suit impervious to water and textured in a manner that will increase cleansing action. Psychological fulfillment can be satisfied in part by the simulated effect of a tub bath. This result arises in a weightless condition from the distribution of warm, soapy water about the body. Biological requirements will be met by working the textured surface over the body. The surfactant effect of this physical effort in conjunction with the soap solution will remove skin microorganisms with each bath. Since there is no residual disinfectant with soap, microbe minimization can be achieved by frequent bathing.

The Bath Suit - Considerable attention has been given to the design of a bath suit and an investigation of a wide variety of materials for use in its fabrication. The key problem lies in the selection of materials. In surveying these materials

the following were considered: gum rubber, estene, mylar, teslar, nouitene, dacron, nylon, rubberized fabric, nylon-mylar laminate (acmetex), and sheet spongecloth. Early in the study, most were judged unsatisfactory because of (1) difficulties in making watertight seals, (2) difficulties in providing textured surfaces to optimize cleaning effectiveness, (3) potential hazards from accidental punctures, (4) inflexibility, (5) fabrication difficulties, and (6) bulk and weight penalties. The survey and subsequent tests indicated that 1/16 inch sheet spongecloth had great merit because of its textured surfaces. This material has a waffle suction pattern on one surface and a serrated pattern on the reverse. Thus one side (serrated) is clearly the abrasive side, the other (waffle) the grasp side. The spongecloth also retains a considerable amount of water. The spongecloth, however, is quite water permeable. Our attempts to enclose it in a waterproof material finally lead to selection of the mylar-nylon laminate. The subsequent suit design and configuration are shown in Figures 2a and 2b. The suit was fabricated by sewing the laminate into the desired shape and size. The seams were then impregnated with an appropriate adhesive to render them impermeable to water. A pressure sealing zipper was incorporated to simplify ingress and egress. A heavy foam rubber collar piece was properly affixed to serve as a seal in the neck. Two quick disconnect fittings were placed in the ankle region for connection to the hose and station. Approximately 30 circles of spongecloth 4 inches in diameter were bonded around the inside (mylar side) of the suit to act analogously to wash cloths.

The advantages of this suit are (1) high flexibility, particularly when wet, (2) waterproof qualities, (3) action as a partial heat insulator, (4) high tear resistance and modular stress strength, (5) an ideal surface for rubbing, (6) relatively simple fabrication, and (7) water retention. The latter property is particularly important in operation in the weightless environment. A more sophisticated design feature would be a modification of the head region in such a way as to encase the head, excepting the face, to facilitate shampooing. The water seal of such a design would constitute a severe problem.

Bathing Procedure - Immersion bathing will be accomplished by donning the suit, adding soap tablets, pumping warm water into the suit, working up a soap solution by agitation, and cleaning by rubbing the fabric over the whole body. The latter action maximizes the surfactant qualities of the solution. Soap will be provided in tablet form; each containing 500 mg soap. It is presently recommended that these tablets be placed in the ankle region near the connectors. With 3000 ml water required for each bath, the bath fluid will be 0.1% soap solution.

The utility of the sponge layer resides in its water retentive qualities. This somewhat complicates the bathing procedure compared by using a plain rubber or plastic suit, but essentially eliminates the problem of fluid loss to the environment. Under weightless conditions this could not be avoided with any other kind of fabric, therefore, the sponge layer will retain a considerable amount of water following bathing. After completion of bathing, the astronaut will work the surplus effluent down to the ankle area, squeezing the sponge layer as well as can be done. When this is pumped out, he will remove the suit and re-zipper it. The residuum of effluent in the suit will be squeezed out as completely as possible and pumped into the central hygiene station reservoir. The water that cannot be expressed by this procedure will be removed by evaporation. Constant air flow over the inside-out suit will rapidly evaporate the last traces of water.

The suit as described weighs about 1.2 kilograms, including connectors. The

sponge layer holds about 2 liters of water and retains about 0.75 liters following squeezing. This 0.75 liters will be finally removed by evaporation as described above.

It will be necessary to carry only one suit as it will be adequate for the entire crew. Until further studies are concluded, each man should bathe on alternate days.

Ulilization of Effluent - After the bath effluent is pumped into the reservoir, it may be further utilized to save capacity of water recovery systems. Ideally, all would be used for other functions without recovery. At any rate, about 430 ml per man per day will be shunted into sanitation, laundering, and dental hygiene. This leaves about 1200 ml which must be processed (Figure 1). If it is possible to use this as potable water, a substantial savings could be effected in the water recovery system capacity.

Superficial Bathing

In addition to whole body bathing, astronauts must be provided with facilities to clean their hands and face at least following meals and elimination. We refer to this operation as superficial bathing. It will be effected by spongecloths wetted with a mild soap solution. The proper solution concentration will preclude rinsing. Drying will be by evaporation.

Two 9 x 7 x 1/8 inch cellulose spongecloths are suggested for this purpose. Optimum wetting requires about 70 cc of solution. Thorough hand and face cleaning leaves about 15 cc of this solution on those body surfaces following the first washing. On subsequent washings less solution is left. About six washings can be effected before the sponge is no longer useable because of the loss of solution.

One sponge per man can be wetted during his immersion bathing. After each time the sponge is used subsequently for cleaning, it will be placed in a small mylar bag within which it will retain moisture. It will be available for use at any time. In cases where excessive demands overdry the sponge, it can be wetted by adding an appropriate quantity of water. A sufficient amount of soap will be available to maintain surfactant qualities from the solution retained in the internal tortuosities of the sponge. Use of the two sponges will allow alternation during the 2-day periods, that not in use being dried to prevent fungal growth.

Dental Care

Dental hygiene will be maintained by utilizing three pieces of equipment: a tooth brush, toothpaste, and a potable water dispenser. The brush recommended is a standard dental professional item. The toothpaste selected has been specified in Section III. It will be contained in and dispensed from tubes in the conventional manner, the water dispenser is required to supply the small amount of fresh water required to brush and clean.

The directions for dental care under weightless conditions follows. It has been devised to eliminate the need of expectorating during and following brushing the teeth. This precludes problems of disposing of the expectorate through other waste treatment methods.

1. Take a small sip of water (about 5cc). Swallow any excess over that amount required to moisten the oral cavity.

2. Extrude a small amount of toothpaste (about 1cc) from tube directly on or into the brush.

3. Brush teeth in the usual way but keep mouth tightly closed around brush. Immediately after brushing, the paste, water, and saliva mixture is swallowed.

4. Take an additional sip of water (about 10 cc) for washing residual paste from teeth and gums. Use the same brush to help in this process. Swallow the water solution of paste. Suck the excess fluid from the brush while drawing it from the mouth.

5. Repeat Step 4. The mouth and brush will both be free from residual paste.

Shaving

Daily removal of facial hair will be achieved by two means. The first will be by a single high efficiency electric shaver that will serve the entire crew. The second will be by an emergency, back-up instrument in the individual gear of each man.

The latter is a dry shaver which is mechanically operated. This machine operates by means of a fixed blade over which moves a rotary perforated cylinder as the machine is moved over the face. Our tests show this type razor may cause some discomfort due to hair pulling, however, this objection can be overcome in part by technique. The best technique involves application by a series of short rapid strokes. The rationale of the mechanical shaver resides in cases of individuals who may develop contact dermatitis. This condition may be transmissible, depending on its etiology; but at any rate would be disconcerting to the other crewmembers.

The shared crew electric shaver must meet some stringent requirements. Several machines on the commercial market have been tested. A primary requisite is non-interference with any electronic gear. This is best met by a shaver with an oscillator motor. This type motor is also associated with high reliability, and ideally has only one moving part. The cover of the shaver must be made of high impact material, or better, one of the new, virtually unbreakable plastics. It must also be capable of withstanding the severe vibrations of take off. It is highly desirable for the machine to retain the bulk of the shavings and be simple to clean. We have found only one machine that will satisfy these specifications. The shaver will be retained by a clip in the upper part of the central hygiene station. Shaving in this position also allows the free shavings to be sucked into the air intake duct and not contaminate the cabin atmosphere.

Nail Care

It has been shown that fingernails will require clipping approximately every two to three weeks. An ordinary commercial nailclipper will be provided for this purpose. A single instrument is included for the entire crew, and will be located in the storage-dryer of the station. Clippings will be collected manually and disposed of in the garbage storage and treatment system.

Laundry

Each crewman will be provided with a laundry bag identical to that described for sanitation. Its use will be dictated by exigency, but each clothing article should be washed after no more than two changes. The bag is large enough to hold a shirt, underpants, "T" shirt, one pair of socks, and a pair of lightweight drawers. It could also separately contain a pair of lightweight coveralls. The volume of the bag is 395 cubic inches. Operative procedure is the same as for the sanitation bag. The bath effluent will be employed to make up the laundry solution. The laundry effluent will have to run directly into the water recovery system because of its high soap and dirt load. Each man will perform the laundry operation following his bath.

SECTION V

INTEGRATION AND FUTURE DIRECTIONS

INTEGRATION

Whatever ultimate design is selected for solving the problems of sanitation and personal hygiene during prolonged space missions, it must obviously be integrated into the entire life support system. At this point, we would like to briefly relate sanitation and personal hygiene hardware, as defined by the program, to other components. These relationships will hopefully serve as a guide to other workers, lest some details be overlooked.

Water Regeneration

Water economy in manned space operations is critical. Therefore, the water relations of sanitation and hygiene demand careful consideration with respect to input and output. Quantity and quality of input and output water will depend on a great many variables. A model of the overall water cycle in the closed system reveals a diversity of pathways, reactions, and physical combinations involving water.

It can be assumed that the influent water supply for sanitation and personal hygiene will contain a relatively constant composition of solutes. What these are will depend on the specific water source, however. Either recovered urine or condensed atmospheric water could be used. Their constituency will depend on the methods and materials of recovery. The presence of airborne debris will certainly contribute to contaminating water of body sources. It can be concluded that the water composition available for input to the central hygiene station is unpredictable at this time. It is highly improbable, however, that any variances of input water will have any effect on its ultimate use. Nevertheless, this aspect should not be neglected. Optimization of the surfactant qualities of soap, methods of soap removal, and subsequent effluent composition depends on this knowledge.

The composition of the effluent solution from each operation of the central station depends on a large number of factors. Perhaps the largest variable will be due to the chemistry and microbiology of the integument of the crew. These will differ from individual to individual and from time to time. The pathway which the effluent follows will further modify its composition. Conclusions as to the fate of the effluent clearly depend on the accuracy of this knowledge. Each of the three possible alternate pathways of the effluent following body bathing outlined in Section III demand further exploration. The net result of using any one of these will be independence of about half (675 ml) of the daily per man bath water effluent from other recovery systems. The apparent necessity of processing laundry and sanitation effluents will add 250 ml daily per man load to the urine recovery system. That system will have to take not only the extra liquid quantity into account, but its composition. The latter will include about a 4% soap concentration.

One important facet of integration will be the mechanism of water-air separation. Following both bathing and laundering, the effluents will consist of a mixture of water in air. Before the water is stored, the mixture will require separation.

For efficiency, particularly weight saving, the separation could best be performed by a component of some other system designed for the purpose. This will involve shunting effluents to and from the device. The design of the central hygiene station is adequate to permit this external procedure.

Atmospheric Debris

A large variety of small particles, aerosols, and vapors will be given off into the cabin atmosphere. This debris can be regulated two ways: by source control and by air conditioning. The first method will be implemented by rigorous specification of component materials of the vehicle and all of its life support equipment. It is patent that the military specification of spaceship hardware include the toxic parameter. Such equipment must further be designed to preclude leakage or volatilization of the materials they contain (e.g., food containers, fuel and water lines, etc.). Minimization of human debris will be effected by regular personal hygiene procedures.

No matter how carefully material selection and personal care are exercised, however, an impressive collection of materials will find their way into the cabin atmosphere. Their removal will constitute a formidable problem as this debris will contain living and physiologically active, in addition to inert, materials. Because of toxic and infectious potentials, all these must be removed from the atmosphere. A number of techniques can be applied to solve the requirement. Selection of the most propitious one depends on several variables: chemical and physical composition of debris, the respiratory gas system, power and weight limitations, and self regenerability.

We believe that the debris must be removed by adsorbtion and absorbtion. Following removal from the cabin air, this debris must be disposed of in some manner as to preclude its reentry into the atmosphere. Disinfection or sterilization of the cabin air; as by UV, freeze out, or superoxide treatment; may be ineffective in themselves. The reason is that the disinfection may still leave a toxic material, or an organism (virus) that may be reactivated.

Relative to the water economy, it must be recalled that the sanitation and hygiene system will introduce some 625 ml of water into the air daily per man. Whatever conditioning system is adopted must take this amount into account as well as the average 1200 ml of insensible water given off daily by each man. Apart from the physiological comfort bestowed by lower relative humidities, the effect of this factor on the microbial population is well known. The relationship is simply one of increased rate of bacterial death with decrease in water content of the air.

Waste Disposal

Provision for disposal of the accumulated wastes from both effluent processing and air filtration is required. Part of the effluent wastes from bathing will become entrapped in the central hygiene station filter. The remainder will stay in solution, pathways for which have been described above. The wastes in laundry and sanitation effluents will be removed by the water recovery system used for urine processing. The only problem will be the disposal of the filter cartridge. We are assuming that the used cartridges will be deposited into the general waste disposal system. As such, the waste receptacles must be sized to accommodate the number of cartridges expected of any given mission duration.

Monitoring

In order to obtain a picture of the sanitary state of the vehicle, atmospheric monitoring will be required. This subject has received considerable attention and has resulted in several studies and proposed solutions. At the very least continuous data should be available to total gas composition, particle size distribution and density, and density of proteinaceous materials. The integrated values of these data can provide an index of the gross probability of microbial growth, as well as its immediate state.

FUTURE DIRECTIONS

In addition to problems of systems integration described above, there lies the necessity of validating the assumptions upon which the design rests. In terms of sanitation and personal hygiene, the essential assumptions concerns precise description of the dirt which must be removed. Especially critical factors involve the fact of a completely closed system which has low total atmospheric pressures, abnormal partial pressures, and a small atmospheric volume per occupant. The terrestrial biosphere represents a huge dilution factor per individual. This situation obviously provides a great deal of inertia with respect to changes of both its biological and physical components. These last pages attempt to outline the major unknowns of the surface of the earth and within space capsules as they contribute to the applied problem of specification of optimal sanitation and personal hygiene hardware.

Microbial Ecology

One of the biological bases of cleanliness is the infectious potential of the variety of microorganisms which will be found in a manned vehicle. The fastidiousness required for alleviating this biological demand depends on predicting the potential. The higher the probability, the greater will be the requirement of removal efficiency. In terms of bulk alone, the total mass of microorganisms expected to be given off to the capsule environment by one man and his accessories will amount to 160 mg per day. This would be equivalent to 9.6 grams over a 60-day flight and would very roughly consist of about 10^{13} individual bacteria, viruses, fungi, and other microorganisms.

The largest part of this staggering number are of no infectious consequence. A small part may be. The almost total void of data on the numbers and varieties of human microbial associates should be filled. Such knowledge would be of practical and far-reaching value to conventional public health in addition to fulfilling a necessary requisite to predictably safe long duration space flight. We believe a program should be instituted to at least assay the microbial populations of individuals selected for astronautic training. The assay should include determination of demographic parameters over different areas of the host. These data should include analyses of variation of populations under different environmental conditions, both of the gross physical environment and of physiological states (e.g., nutrition). Particular attention should be given to the effects of the conditions in closed ecological systems with the inherent crowding.

Information on the viability of free microorganisms in cabin environments would be significant in the design of air conditioning systems. Such data are nonexistant. Clearly the population dynamics of the man-microbial system demands precise

description. The effects of weightlessness on the system must be at least superficially understood. Similarly, anticipated high event radiations should be investigated for the purpose of predicting their effects on genetic variation.

The performance of these assays and experiments will not be simple. One of the major technical difficulties will be the operational one of setting up laboratory procedures to differentiate the spectrum of bacteria, fungi, viruses, actinomycetes, protozoa, etc. which compose the human microbial eco-system. A second difficulty will involve duplication of two environmental parameters - weightlessness and radiations on human subjects. In regard to the latter point, the intimate nature of host parasite relations is such that in vitro procedures could lead to erroneous conclusions.

The inherent dangers of pathogenicity from all sources in the capsule eco-system can be more simply predicted pragmatically. This approach has been used exclusively heretofore in engineering life support equipment. Thus, indicants such as evidence of coli-forms in the effluents of urine recovered water or atmosphere condensates have provided standards for water potability. Such tests are of unquestioned value to public health. Extension of these techniques to evaluate sanitation and hygiene systems in long aerospace missions is highly questionable. Likewise, the efficiency of sterilizing techniques on test organisms, such as airborne B. subtilis spores, may not be extrapolated to other forms. Perhaps the most superficially convincing tests of systems performance lie in human viability itself. If an individual goes through a long simulated flight without ill effect, the null hypothesis is accepted and the system along with it. No cognizance is taken of the multiplicity of biological phenomena occurring during the test. Similarly, the large departures of the test conditions from true space flight appear to be overlooked in the micro-biological context. The large variations in individual interactions with the microbial populations are also overlooked.

We suggest that some effort be directed towards an understanding of the man-microbe relationship. This will include description of micro-population structure as well as the factors affecting its variations. The enormity of such an undertaking, identical in scope to the ultimate goal of the study of infectious disease, should not discourage its attempt. The attempt itself will add confidence to man's ability to overcome this, another of the many stresses of space flight.

Toxicology

A diverse collection of biologically active materials will be given off into the capsule environment. The outline given in the first part of this report gives a number of these and their calculated rates of generation. The true situation may be considerably different. Investigations should be instituted to more precisely determine what these materials might be. These materials will arise from four major sources:

1. Man himself
2. Human microbial associates
3. External sources (fuels)
4. Cabin interior and equipment.

They can be classified into the following heuristic categories:

1. Those materials which must be excluded at all costs.
2. Those materials for which substitutes should be sought, but for which, if they cannot be found, must be identified and controlled in flight.
3. Those materials which, at expected concentrations, are not toxicologically limiting.

It is obvious that those products given off by man and his microbial associates cannot, by definition, be avoided. In order to create an engineered habitable environment, however, they should be appreciated. The current state of knowledge on the subject stands in need of expansion. Both qualitative and quantitative estimates of all the materials present as vapors, gases, and particles is almost completely conjectural, particularly in reference to conditions in a closed system in outer space.

In addition to the incompleteness of data describing what materials may be present, there is but a limited understanding of the mechanisms involved in their effect. The nature of penetrability of the skin is not understood. Clearly, more information on this subject would lead to greater precision in scheduling bath procedures. Limiting thresholds of exposure to various compounds could also be better prescribed with such information.

SECTION VI

CONCLUSIONS

The data and estimates of waste products and rates of their generation expected to obtain in manned space flight have been more or less exhaustively presented. This compendium, however, can serve only as a rough guide. As with all biological systems, the variances of the numbers can be expected to be exceedingly large. These variances are due to different inherent individual characteristics and interaction of those individuals with the conditions of the space environment. The latter are essentially unknown and unpredictable at this time. The components and materials described for effecting cabin sanitation and personal hygiene are based on the assumption of quasiterestrial conditions. These parameters must be regarded as conjectural until further data become available.

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Unclassified report

The purpose of this study was to determine a means of providing astronauts with facilities for performing the functions of personal hygiene and sanitation while on extended aerospace missions. Included is a definition and analysis of the sources of "dirt" arising as

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3. Hygiene
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III. Contract AF 33(616)-7754
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